

**LA-UR-22-20609**

**Approved for public release; distribution is unlimited.**

**Title:** Kilonova Detectability with Wide-Field Instruments

**Author(s):** Chase, Eve Adde

**Intended for:** Invited Seminar: Fermilab Cosmic Physics Center

**Issued:** 2022-01-25



Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by Triad National Security, LLC for the National Nuclear Security Administration of U.S. Department of Energy under contract 89233218CNA00001. By approving this article, the publisher recognizes that the U.S. Government retains nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy. Los Alamos National Laboratory strongly supports academic freedom and a researcher's right to publish; as an institution, however, the Laboratory does not endorse the viewpoint of a publication or guarantee its technical correctness.



# Kilonova Detectability with Wide-Field Instruments

Eve A. Chase

January 31, 2022

LANL LA-UR: #####

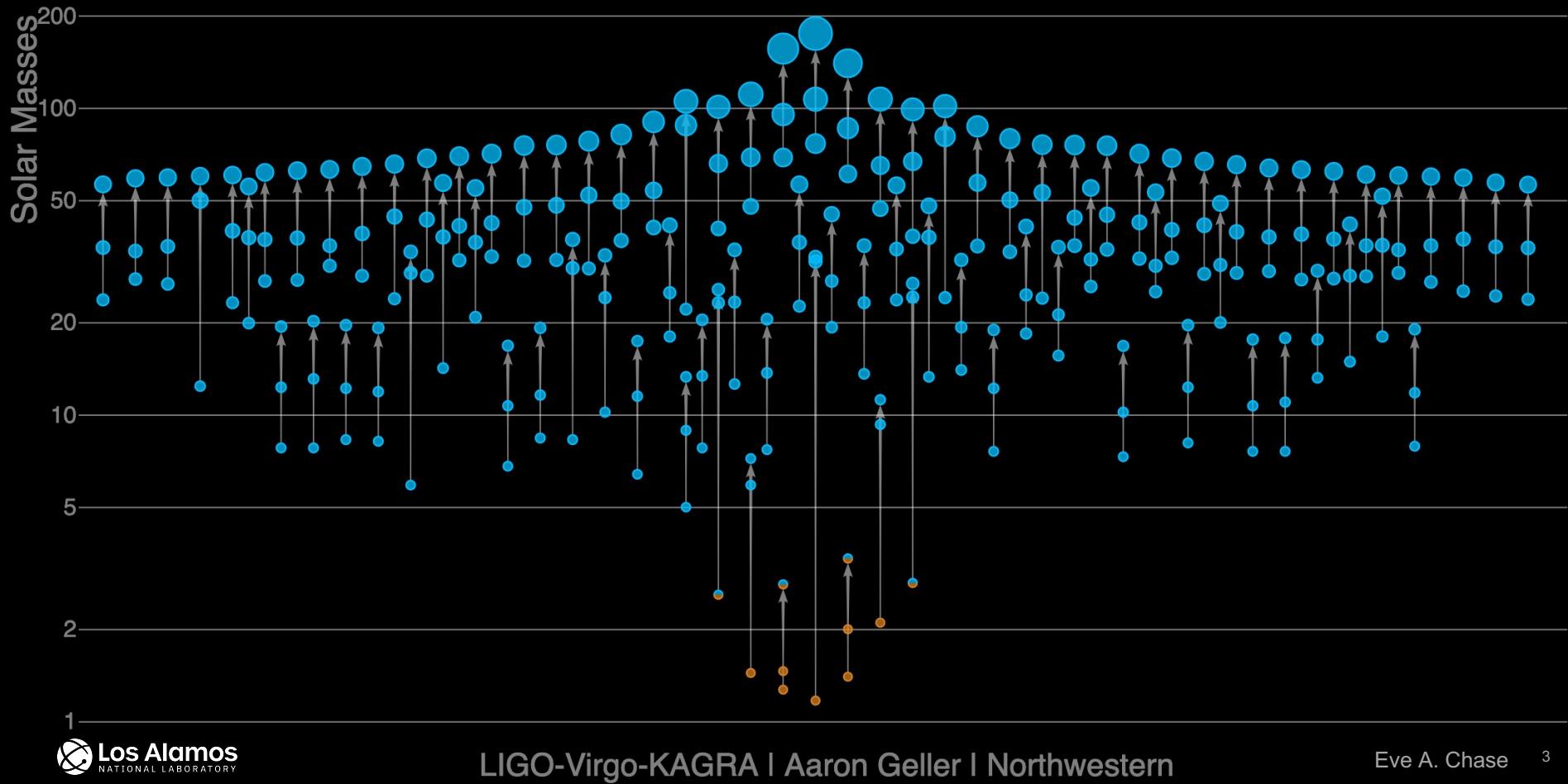
# Chase et al. 2022

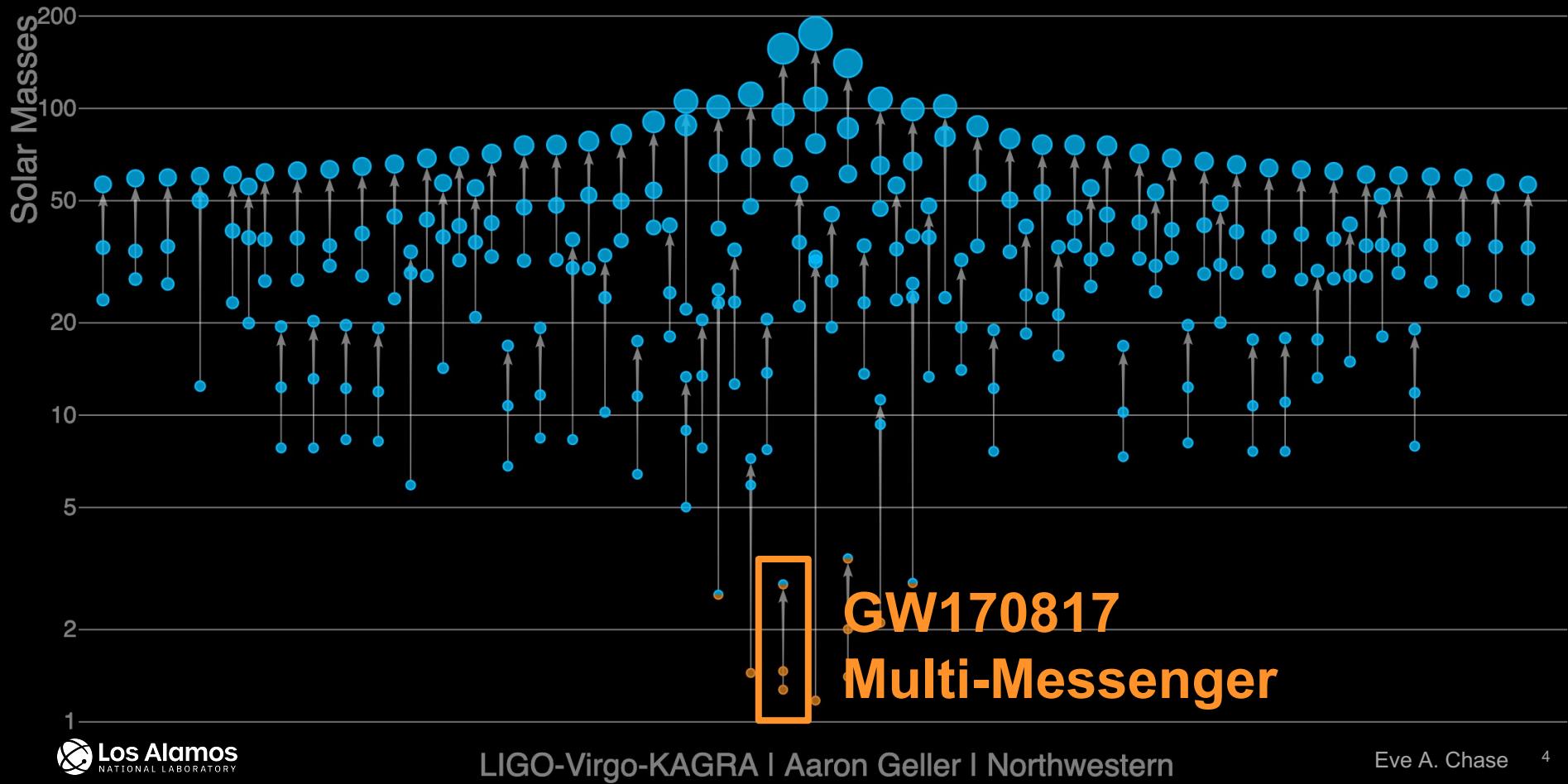
Accepted by ApJ

arXiv: 2105.12268

## Collaborators:

Brendan O'Connor, Chris Fryer, Eleonora Troja, Oleg Korobkin, Ryan Wollaeger, Marko Ristic, Chris Fontes, Aimee Hungerford, and Angela Herring





Painting Credit:  
Karelle Siellez

# Neutron Star Mergers

Gravitational  
Waves

EM  
Emission

# Neutron Star Mergers

General relativity

Gravitational  
Waves

EM  
Emission

# Neutron Star Mergers

General relativity

Stellar astrophysics

Gravitational  
Waves

EM  
Emission

# Neutron Star Mergers

General relativity

Stellar astrophysics

Neutron star  
equation of state

Gravitational  
Waves

EM  
Emission

# Neutron Star Mergers

General relativity

Stellar astrophysics

Neutron star  
equation of state

Heavy element  
formation

Gravitational  
Waves

EM  
Emission

# Neutron Star Mergers

General relativity

Stellar astrophysics

Neutron star  
equation of state

Heavy element  
formation

Cosmology

Gravitational  
Waves

EM  
Emission

# Neutron Star Mergers

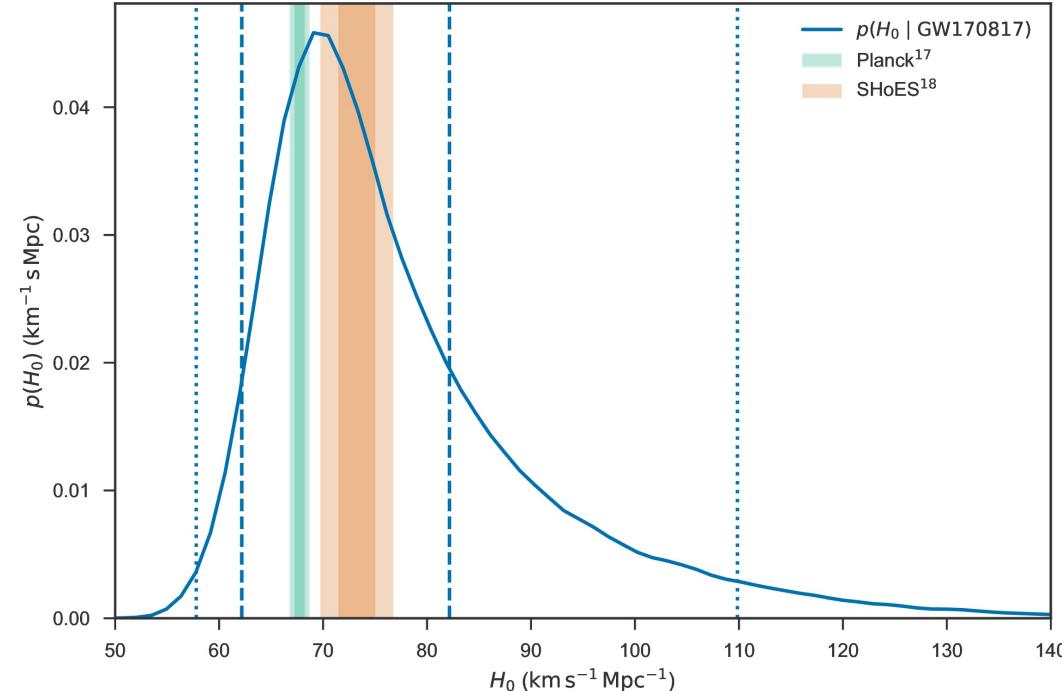
General relativity

Stellar astrophysics

Neutron star  
equation of state

Heavy element  
formation

Cosmology



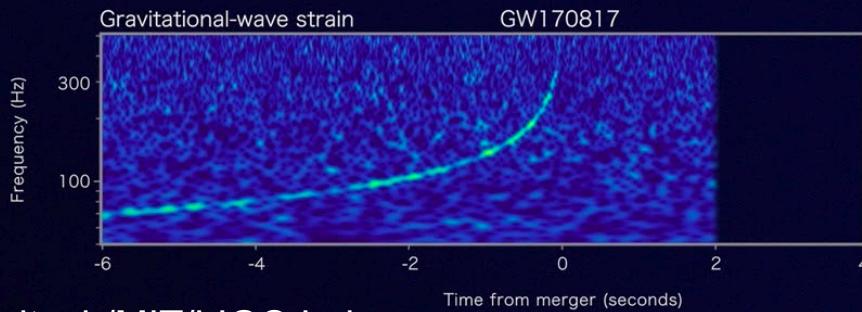
LVC et al. (incl. Chase) 2017, arXiv: 1710.05835

Painting Credit:  
Karelle Siellez

# Neutron Star Mergers

Gravitational  
Waves

LIGO



Credit: NASA GSFC & Caltech/MIT/LIGO Lab

Painting Credit:

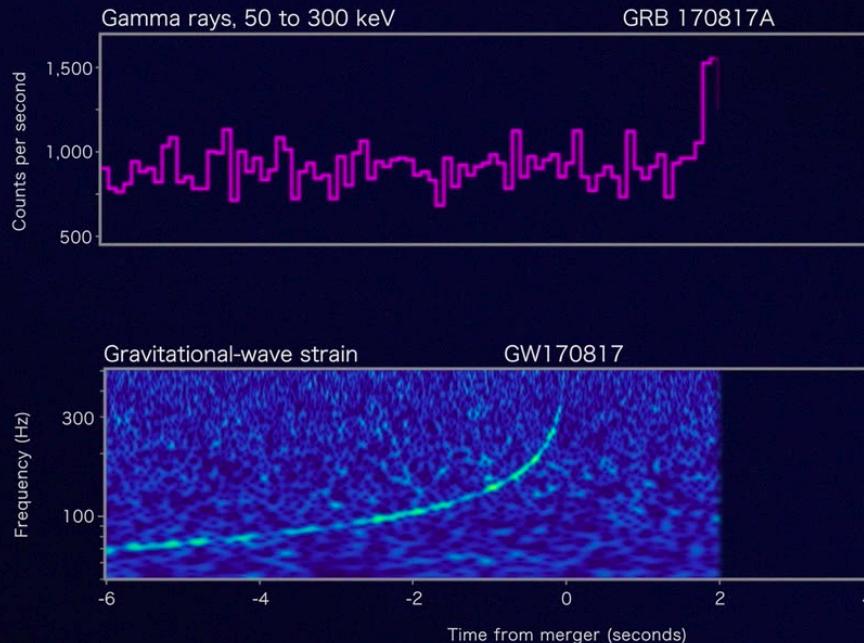
Karelle Siellez

# Neutron Star Mergers



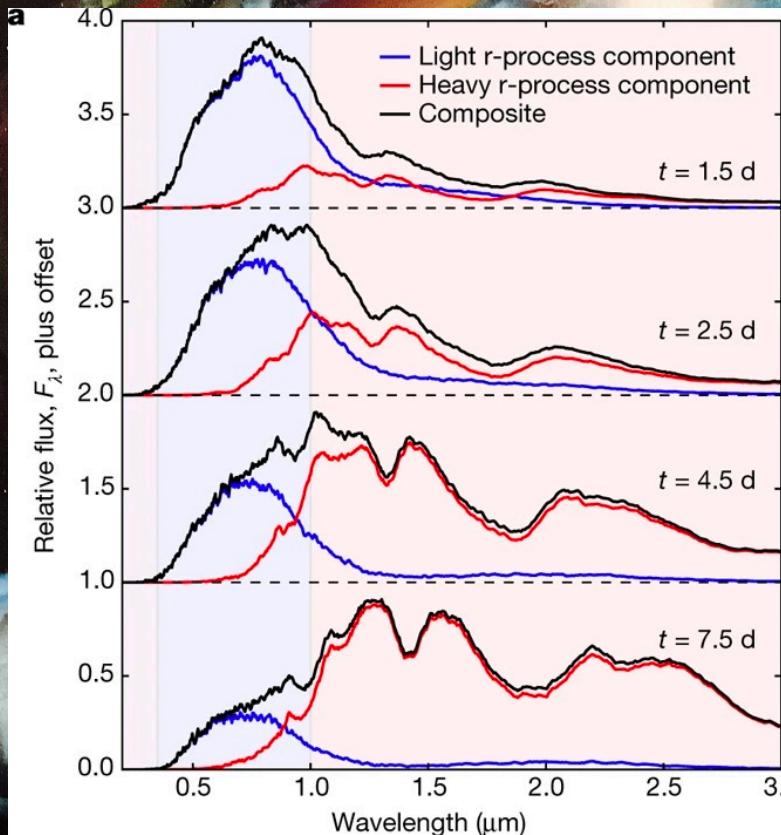
Fermi

LIGO



Credit: NASA GSFC & Caltech/MIT/LIGO Lab

# Neutron Star Mergers



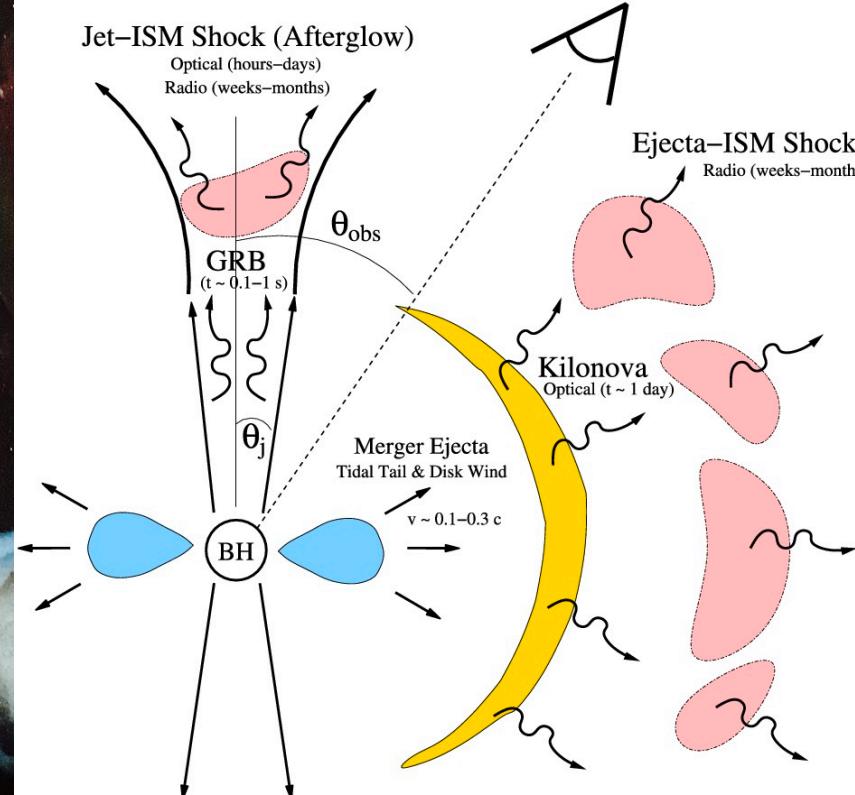
Kasen et al. 2017; arXiv: 1710.05463

Gravitational  
Waves

Gamma-ray  
Burst

Kilonova

# Neutron Star Mergers



Metzger & Berger 2012; arXiv: 1108.6056

Gravitational  
Waves

Gamma-ray  
Burst

Kilonova

Afterglow

# Neutron Star Mergers

General relativity

Stellar astrophysics

Neutron star  
equation of state

Heavy element  
formation

Cosmology

Gravitational  
Waves

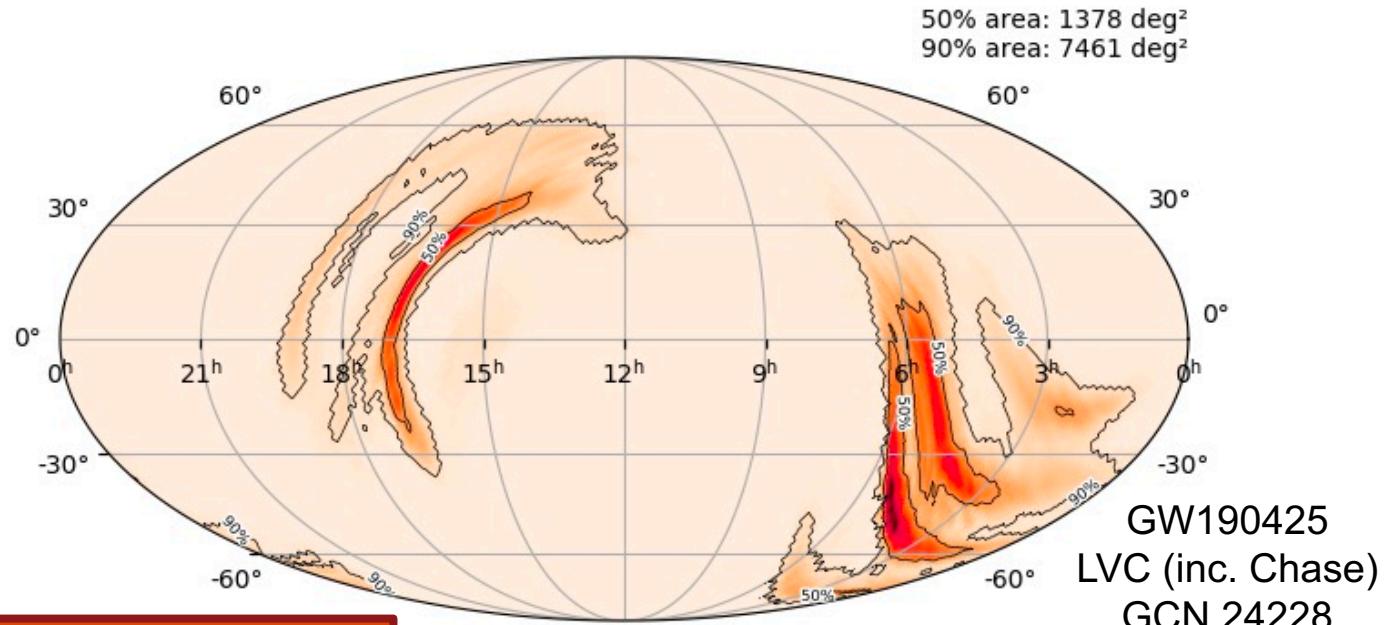
Gamma-ray  
Burst

Kilonova

Afterglow

# Searching for a Kilonova

# Searching for a Kilonova



Full moon only covers  
0.2 deg<sup>2</sup> of the sky

# LANL Kilonova Simulations

- **Radiative transfer simulations**
  - SuperNu (Wollaeger et al. 2013; Wollaeger & van Rossum 2014)
- **Multi-dimensional simulations yielding spectra and lightcurves of kilonovae**
- **Relies on LANL suite of atomic physics codes**
  - Fontes et al. 2015; Fontes et al. 2020
- **Relies on nucleosynthesis results from WinNet code**
  - Winteler et al. 2012; Korobkin et al. 2012
- **Input decay product thermalization model**
  - Barnes et al. 2016

# LANL Kilonova Simulations

- **New simulations recently made public**
  - Wollaeger, Fryer, Chase et al. 2021 (arXiv: 2105.11543)

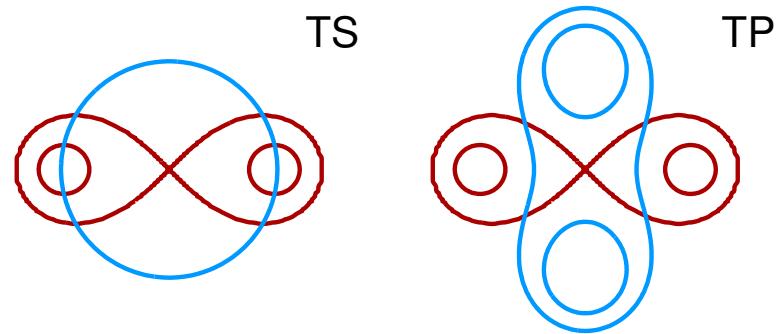
**Publicly available:** <https://zenodo.org/record/5745556>

- **Used in several previous publications**

- |  |   |
|--|---|
| <ul style="list-style-type: none"><li>▪ Evans et al. 2017</li><li>▪ Kasliwal et al. 2017</li><li>▪ Tanvir et al. 2017</li><li>▪ Troja et al. 2017</li><li>▪ Wollaeger et al. 2018</li><li>▪ Wollaeger et al. 2019</li><li>▪ Even et al. 2020</li></ul> | <ul style="list-style-type: none"><li>▪ Thakur et al. (inc. Chase) 2020</li><li>▪ O'Connor et al. (inc. Chase) 2021</li><li>▪ Korobkin et al. (inc. Chase) 2021</li><li>▪ Bruni et al. 2021</li><li>▪ Ristic et al. (inc. Chase) 2021</li><li>▪ Dichiara et al. (inc. Chase) 2021</li><li>▪ Chase et al. 2022</li></ul> |
|--|---|

# LANL Kilonova Simulations

- **Dynamical ejecta**
  - Low- $Y_e$ , lanthanide-rich, “red”
- **Wind ejecta**
  - High- $Y_e$ , lanthanide-poor, “blue”

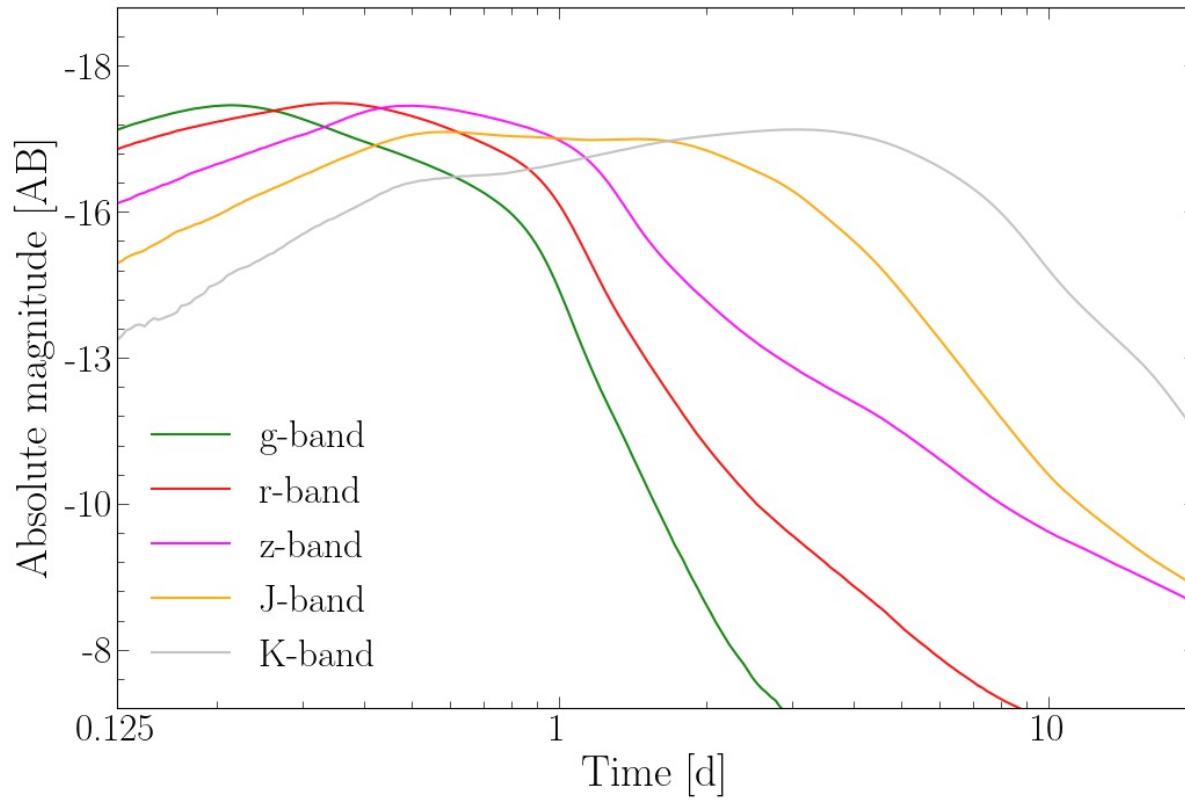


900 simulations!

**Table 2.** Properties of LANL kilonova simulations (adapted from Wollaeger et al. 2021).

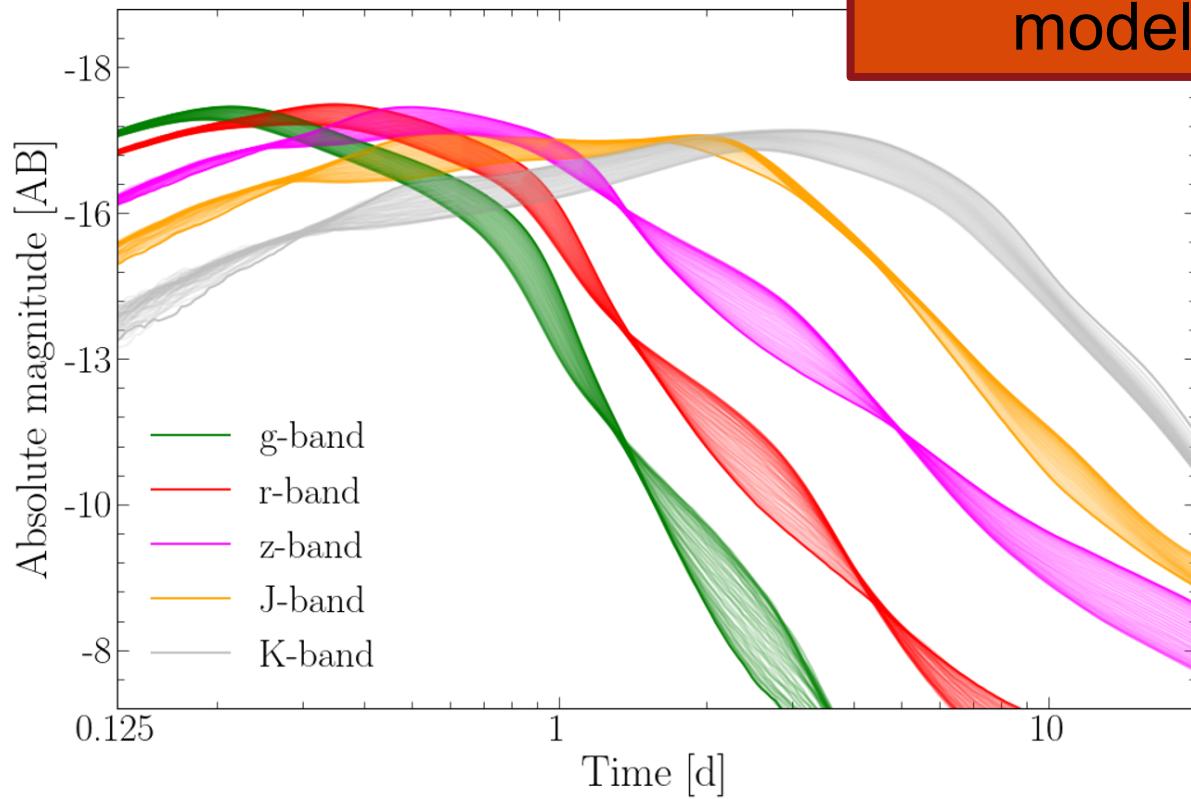
Property	Values
Dyn. ejecta mass	{0.001, 0.003, 0.01, 0.03, 0.1} $M_\odot$
Wind ejecta mass	{0.001, 0.003, 0.01, 0.03, 0.1} $M_\odot$
Dyn. ejecta velocity	{0.05, 0.15, 0.3} $c$
Wind ejecta velocity	{0.05, 0.15, 0.3} $c$
Dyn. ejecta morphology	Toroidal (T; Cassini oval family; Korobkin et al. 2021)
Wind ejecta morphology	Spherical (S) or “Peanut” (P; Cassini oval family; Korobkin et al. 2021)
Dyn. ejecta composition	initial $Y_e = 0.04$ (see Table 2 in Wollaeger et al. 2021)
Wind ejecta composition	initial $Y_e = 0.27$ or $0.37$ (see Table 2 in Wollaeger et al. 2021)

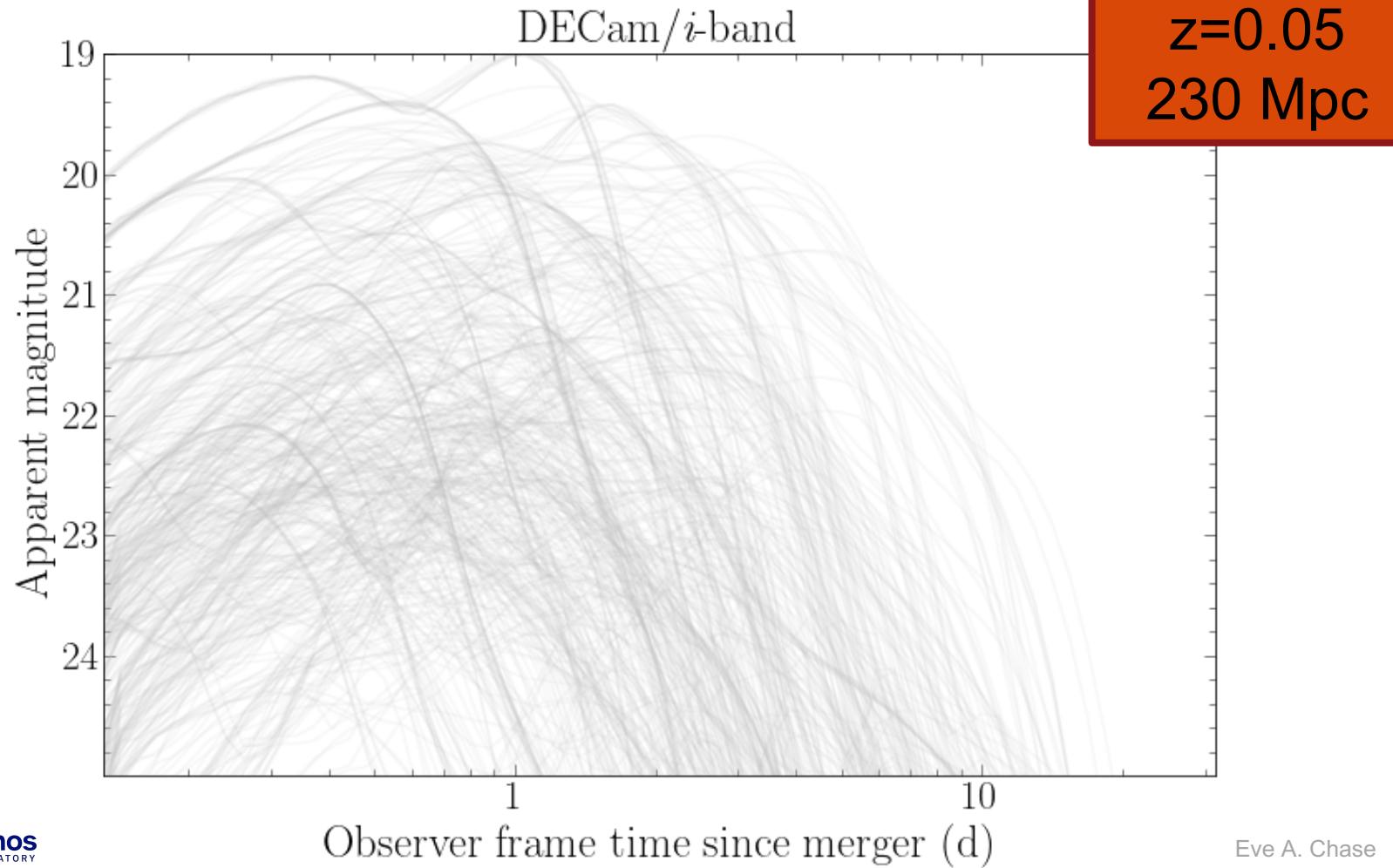
# Kilonova Lightcurves

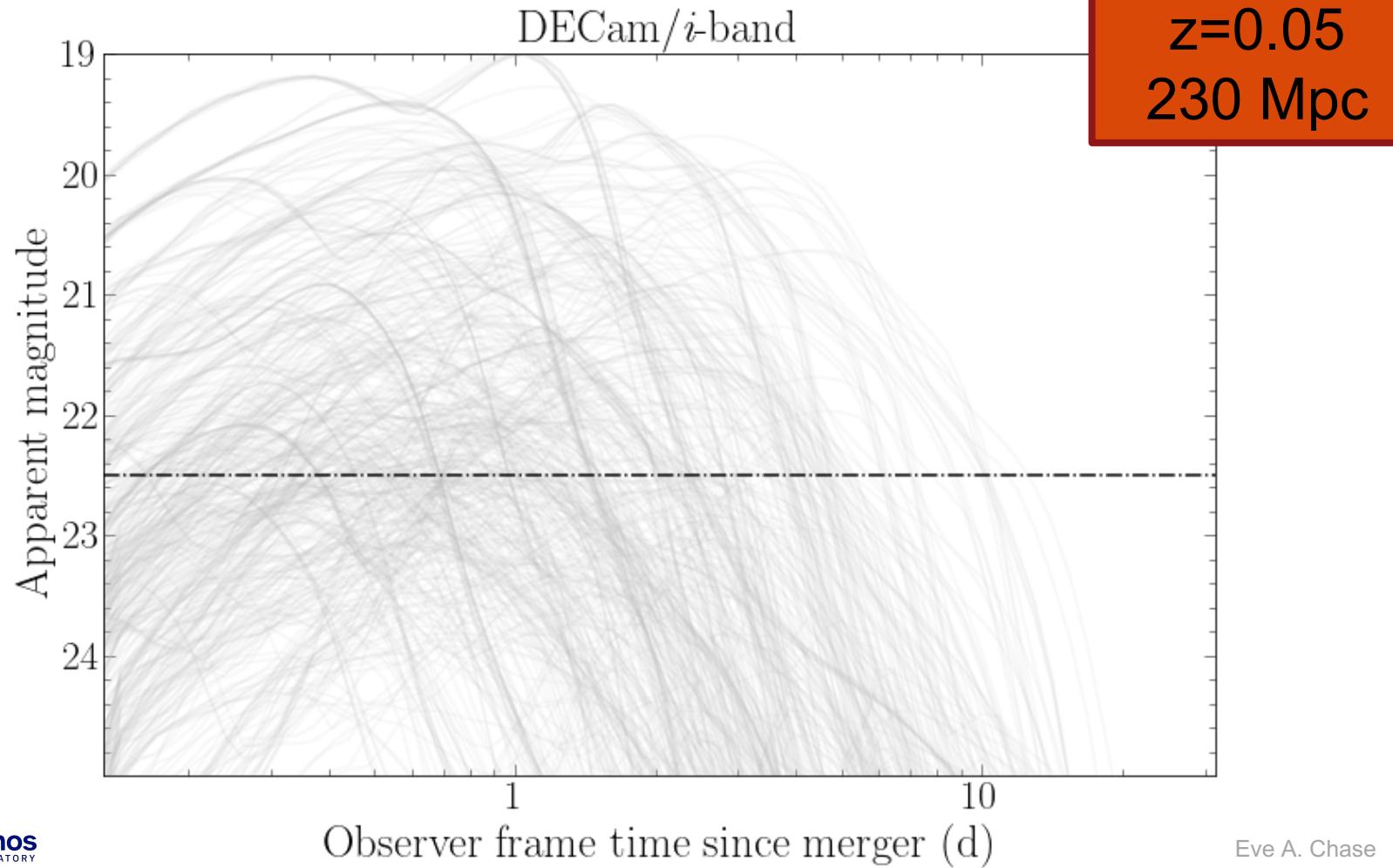


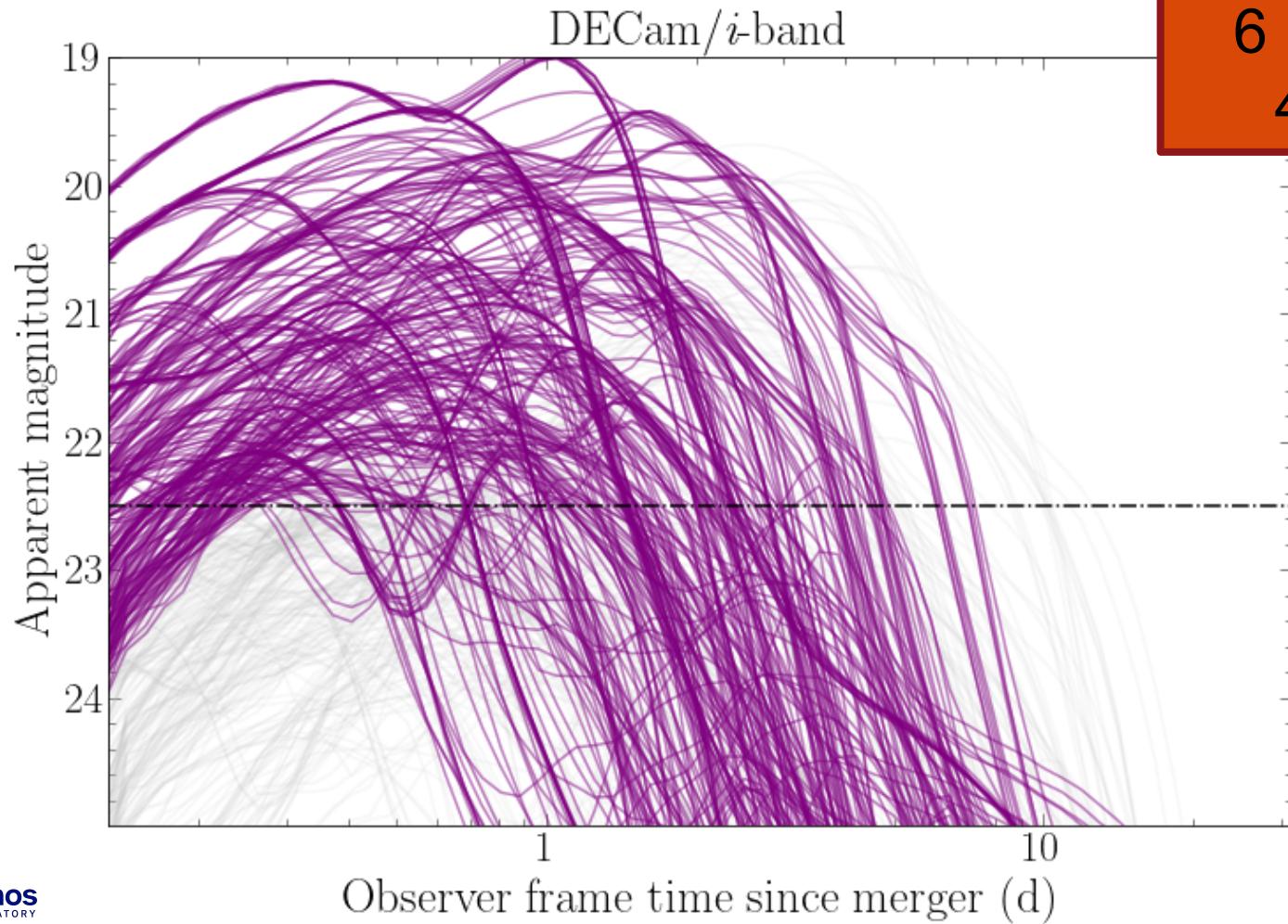
# Kilonova Lightcurves

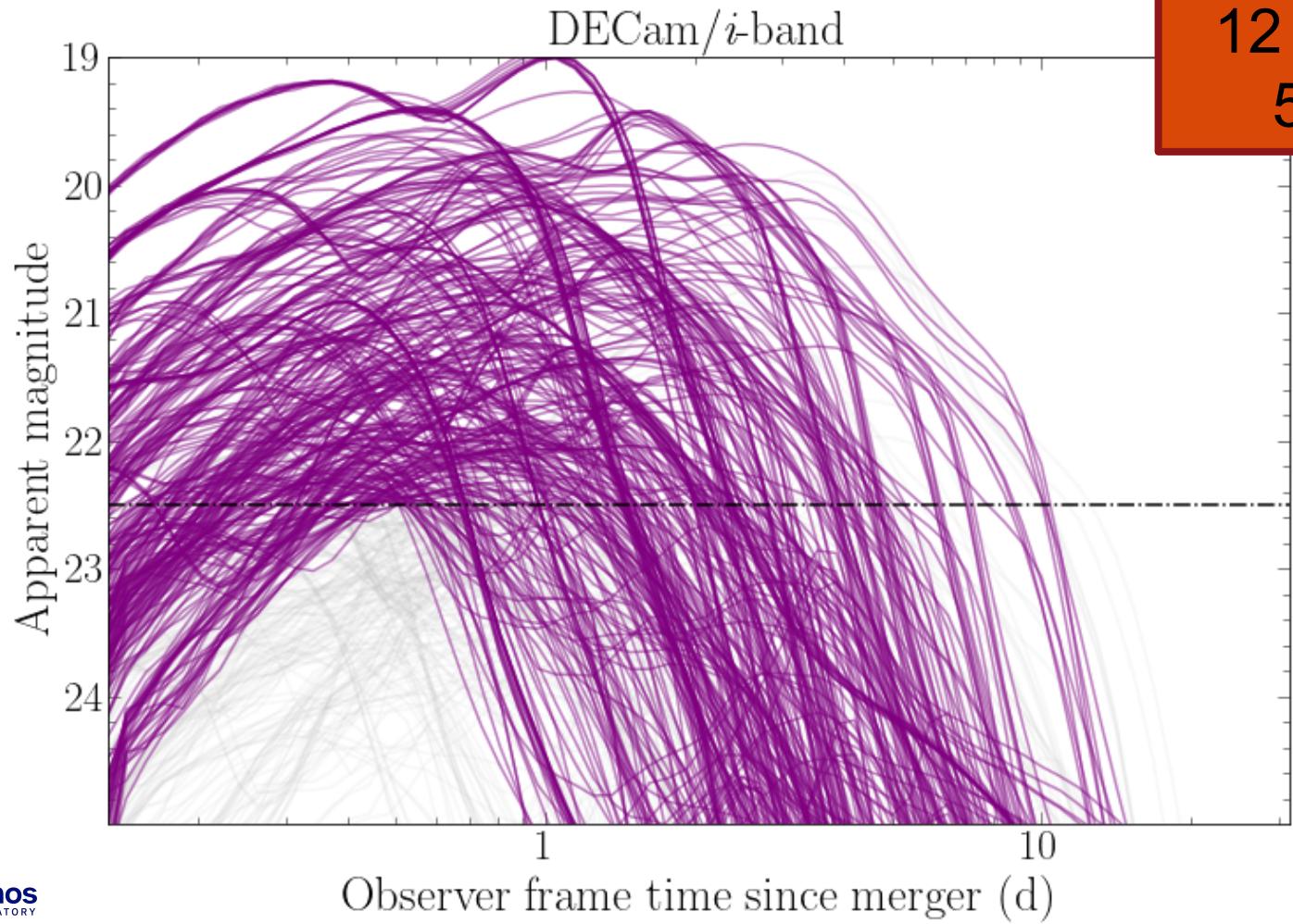
900\*54 = 48,600  
models!

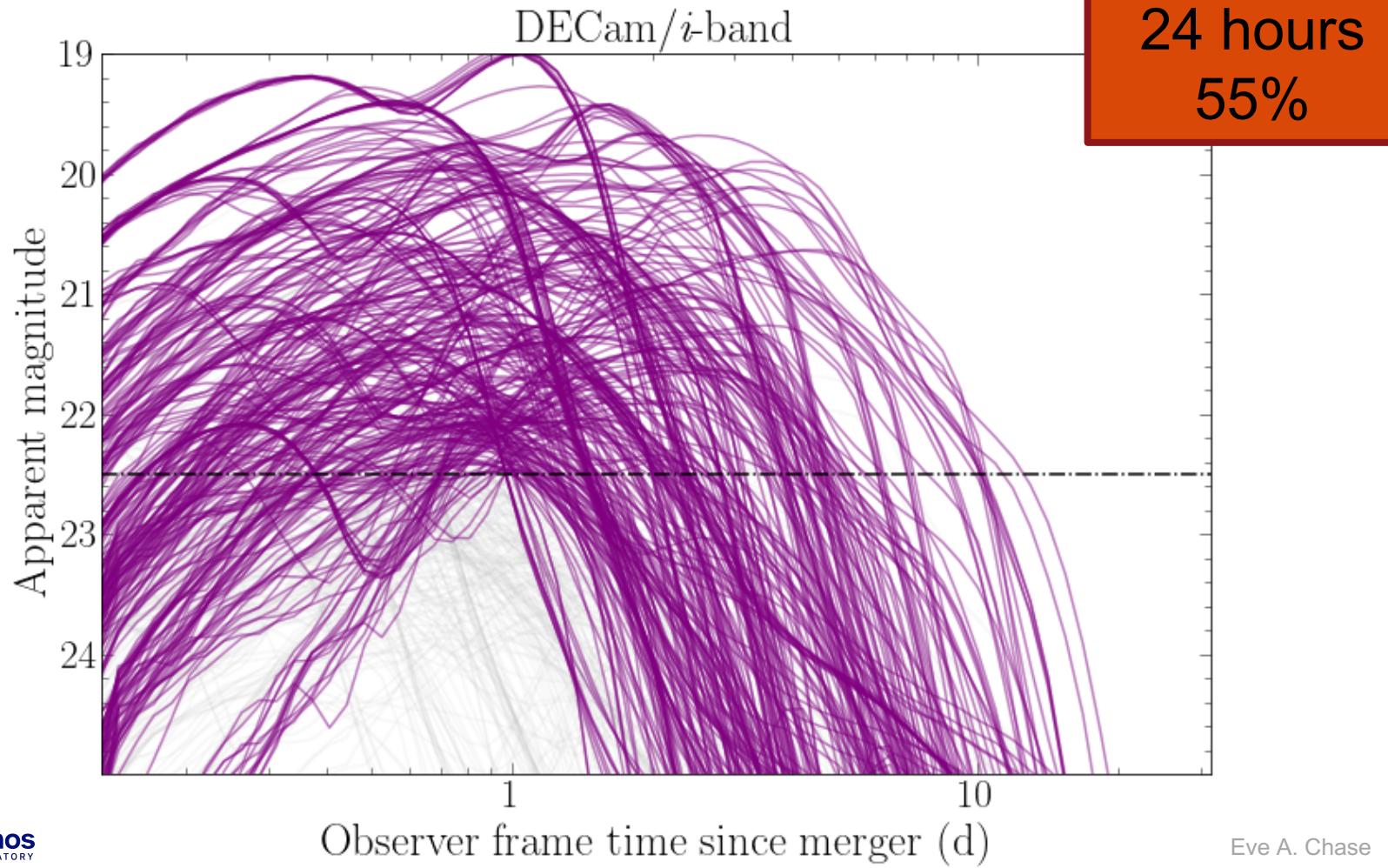


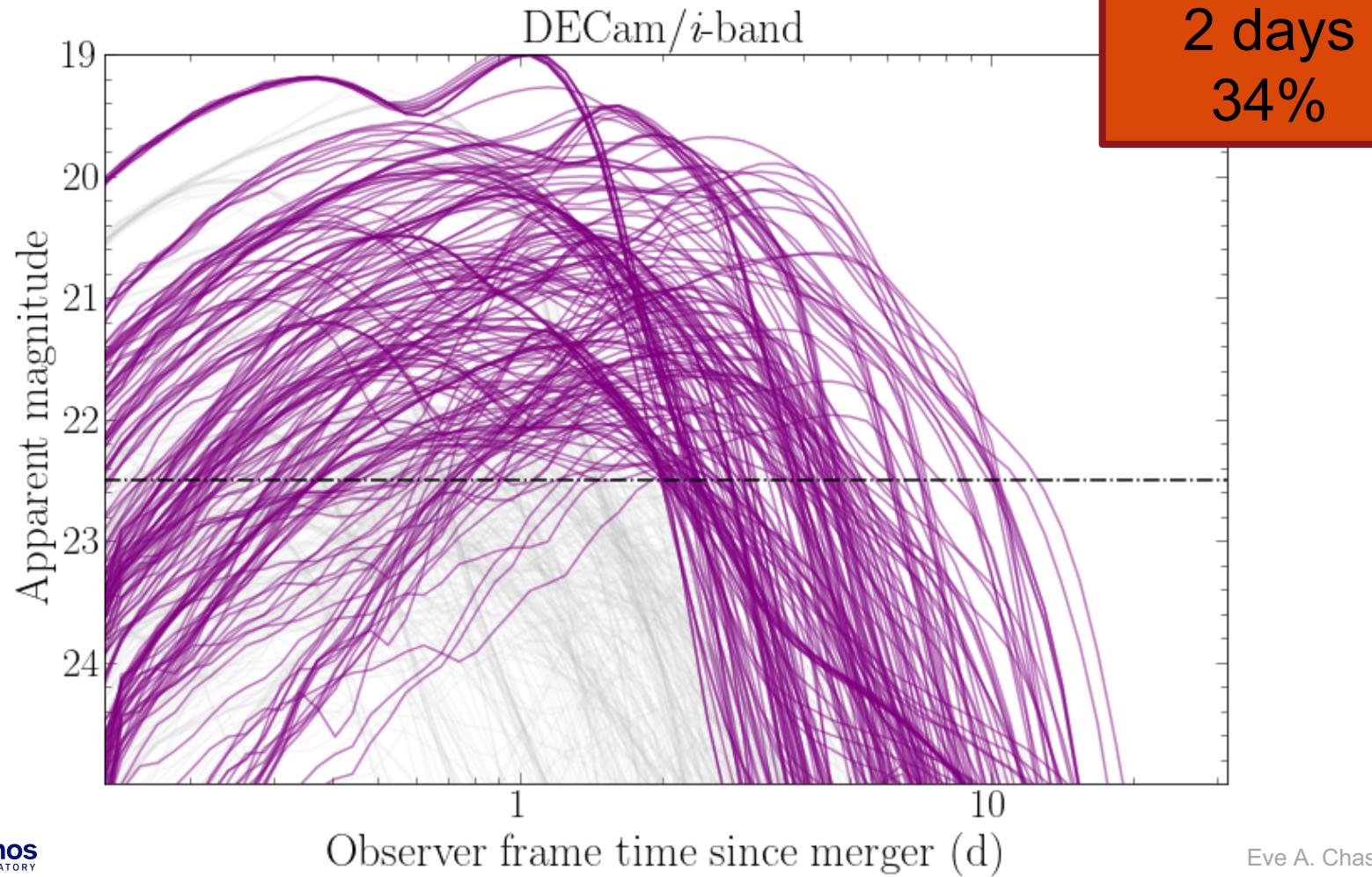


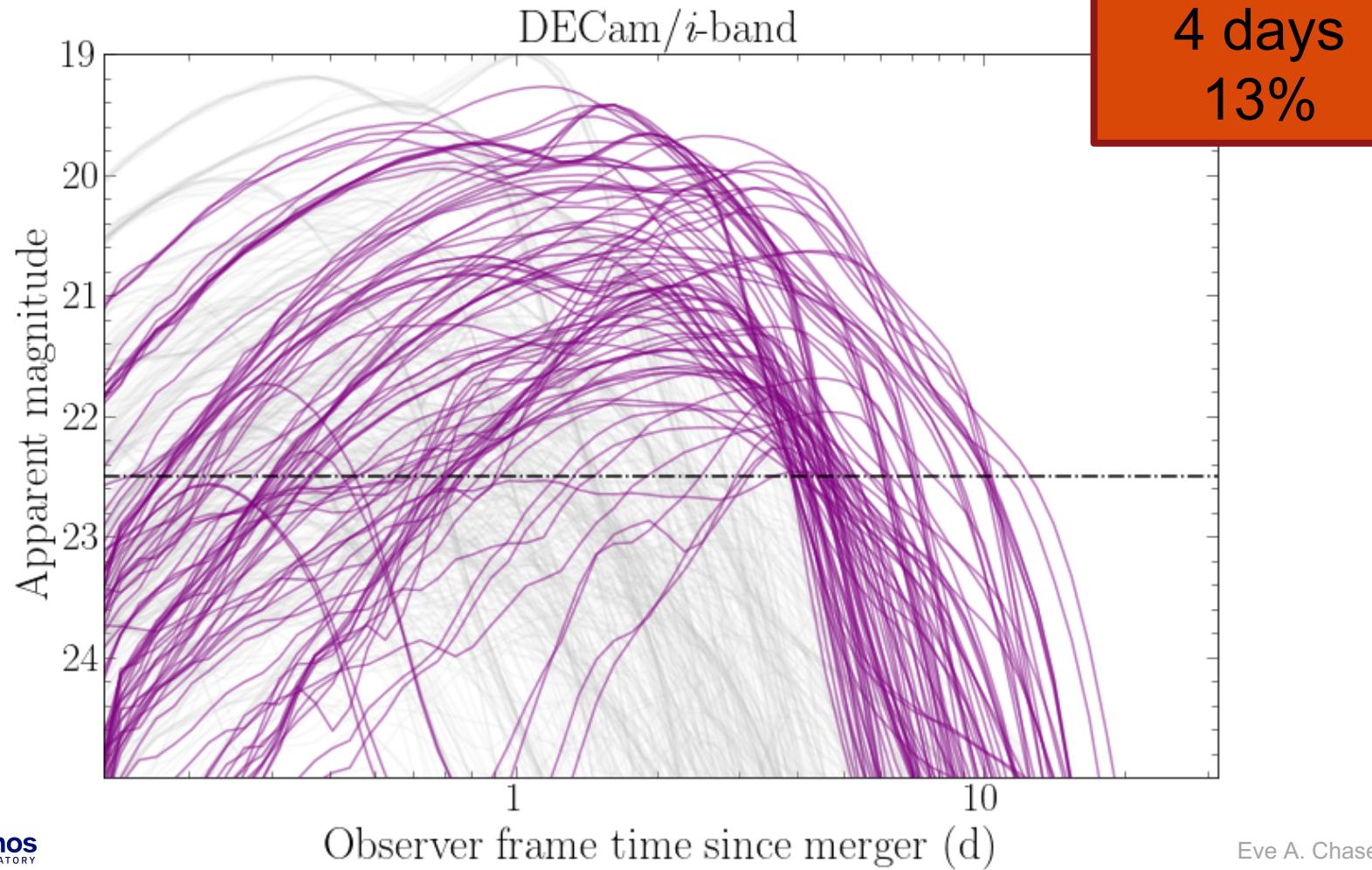


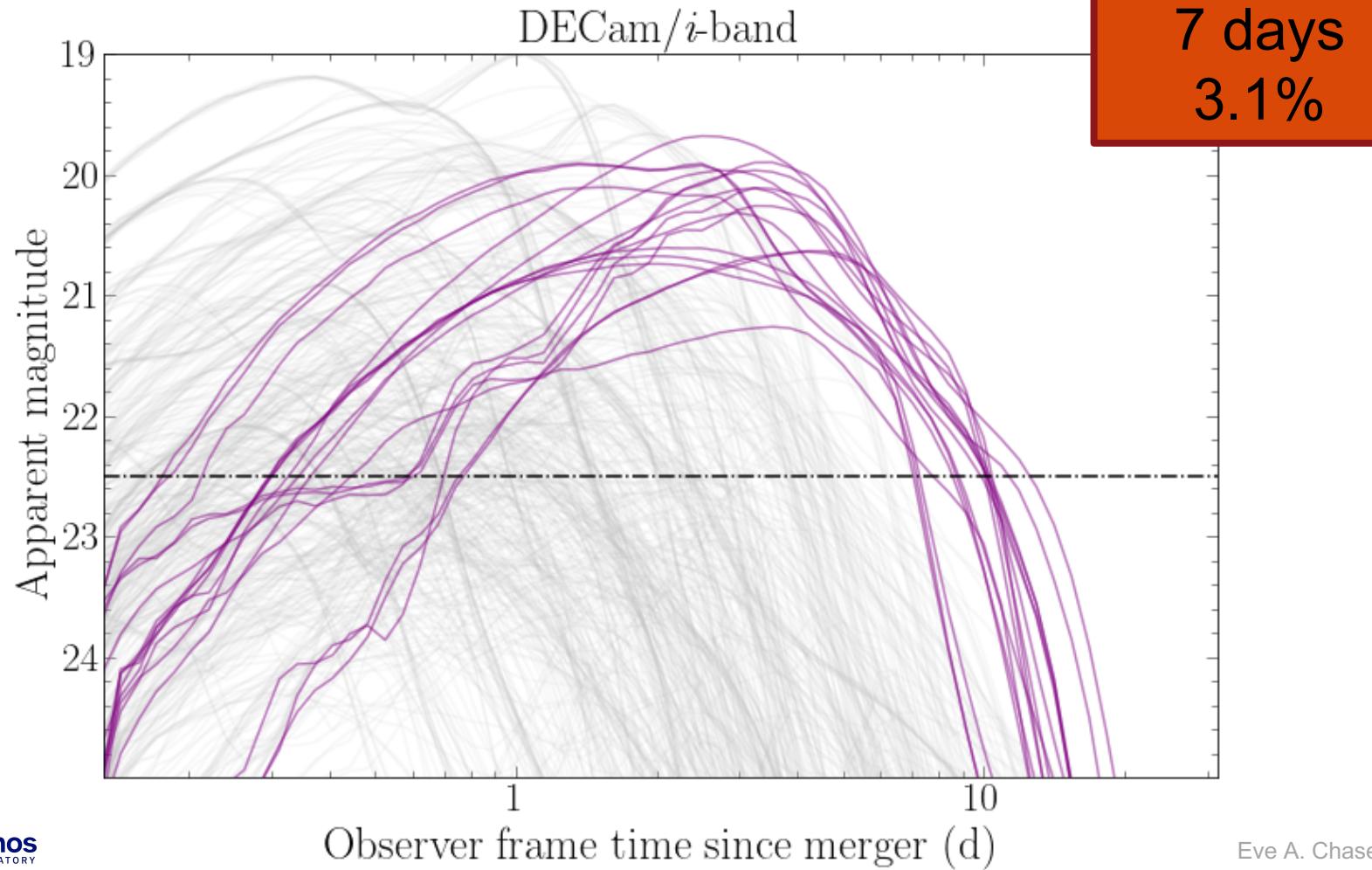


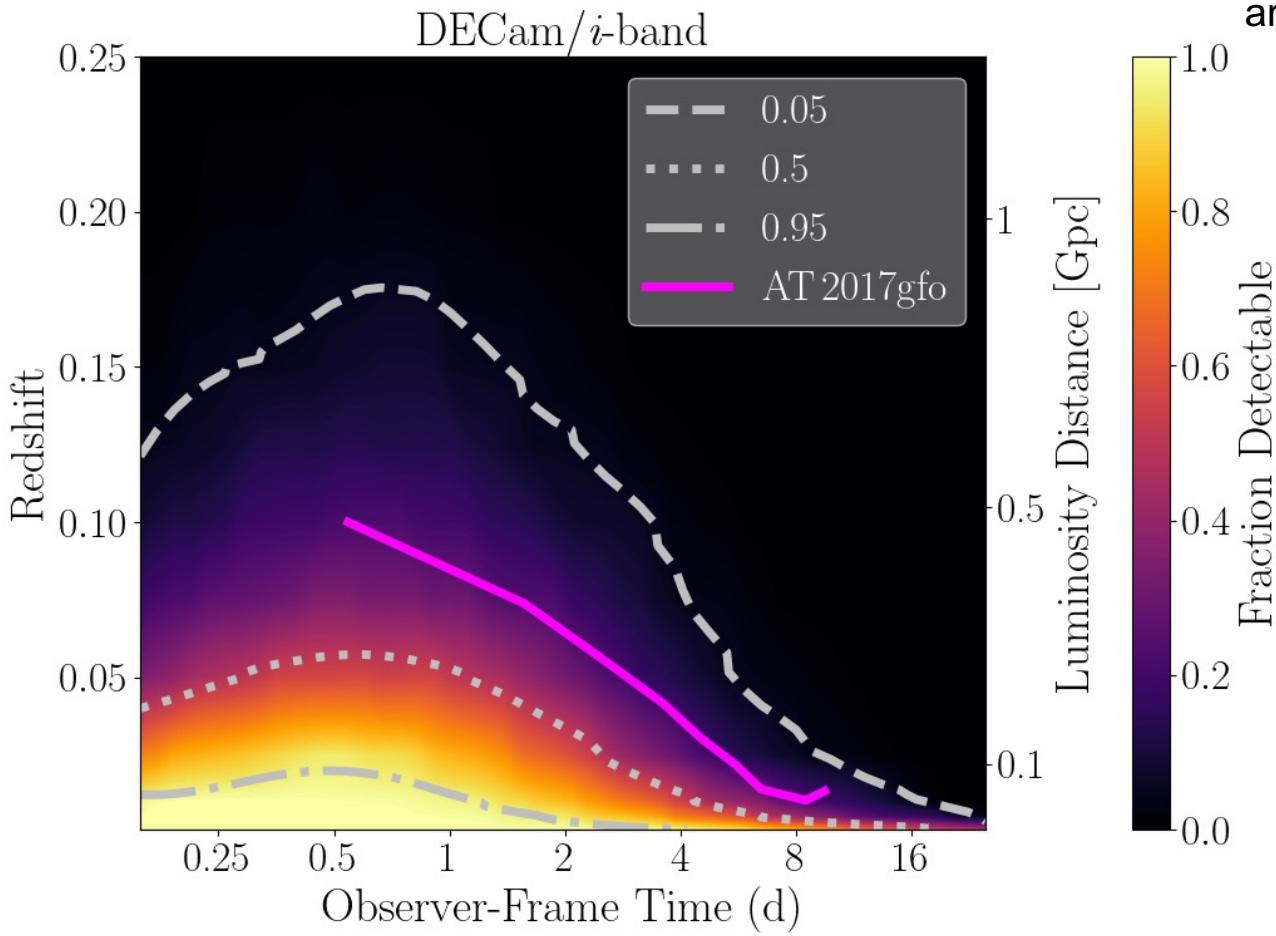


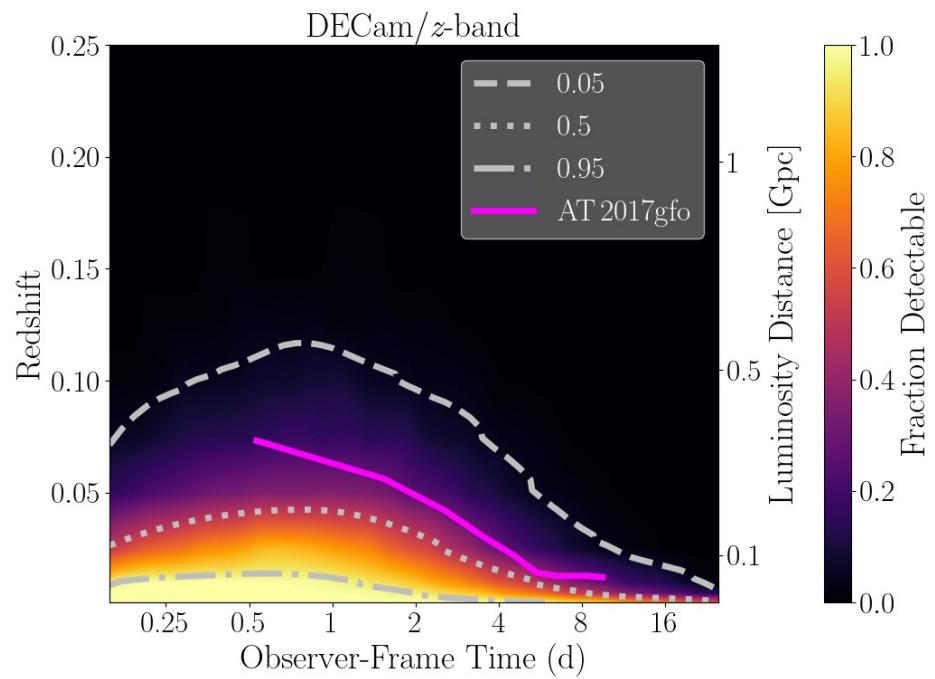
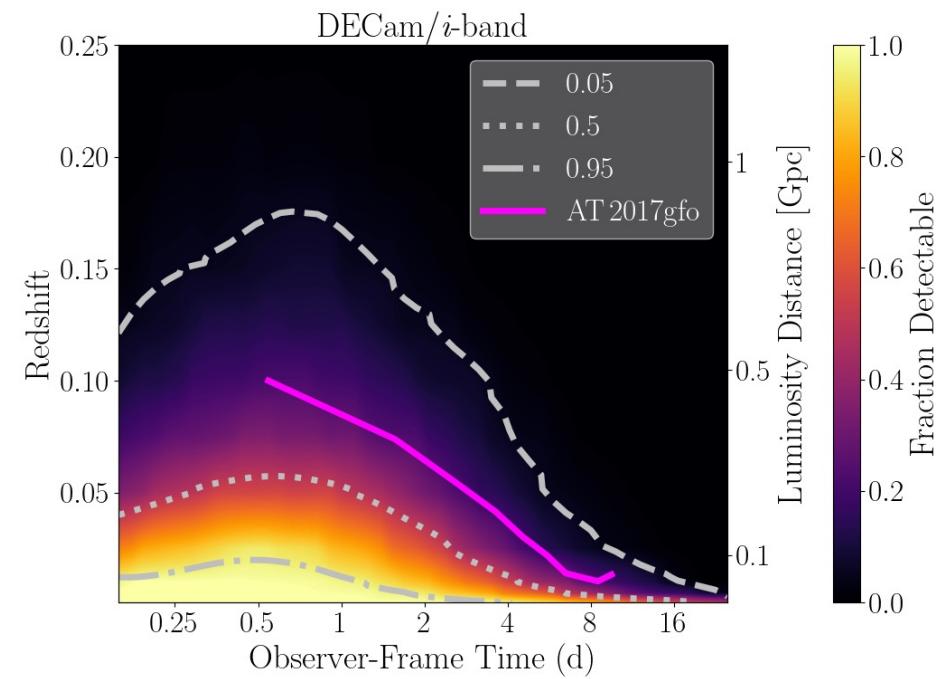




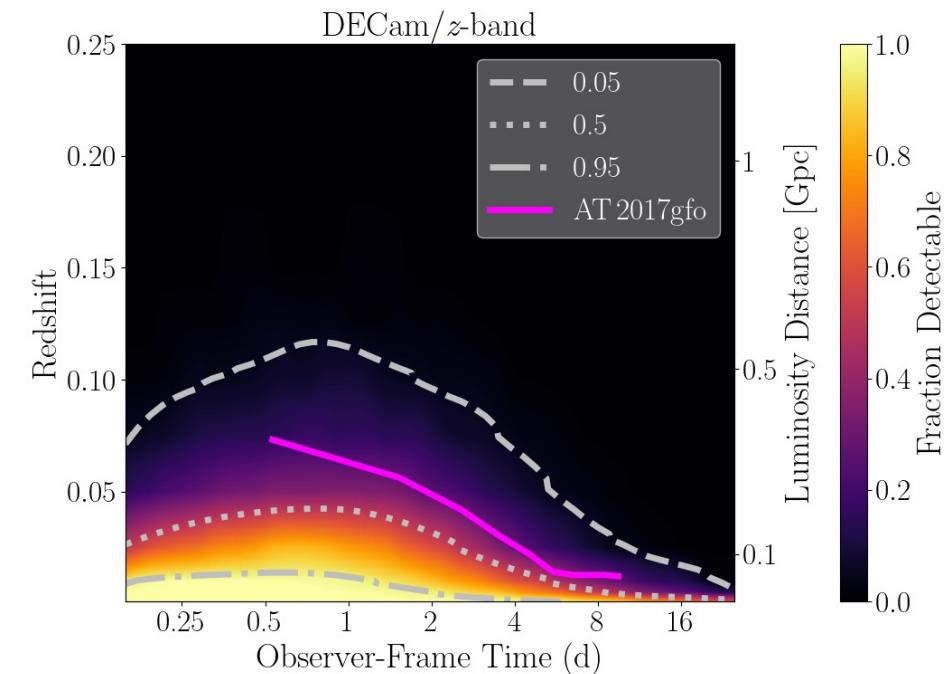
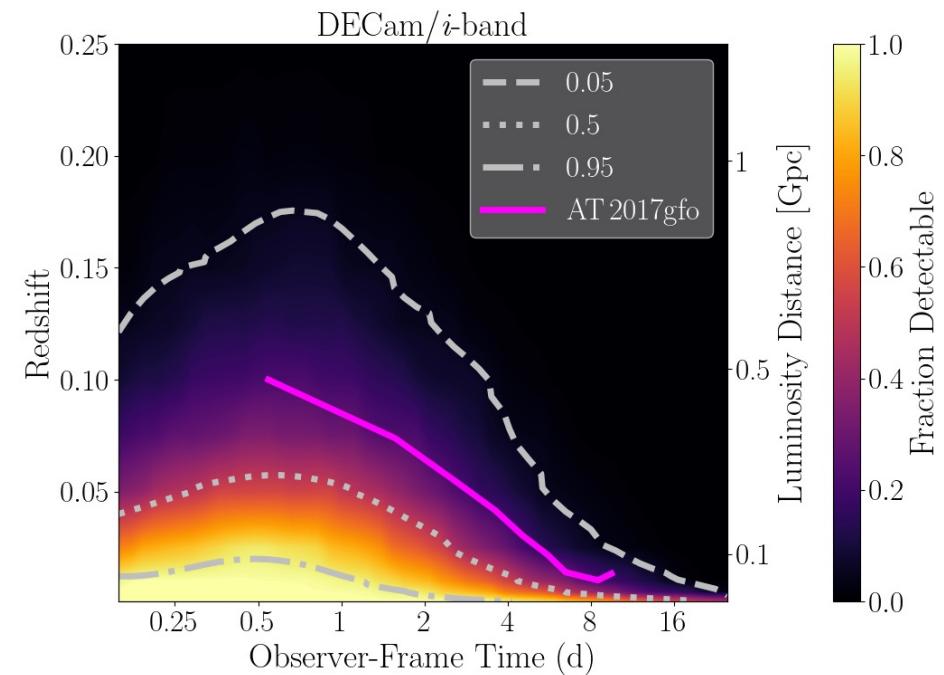








# Almost every KN observable in z-band is also observable in i-band

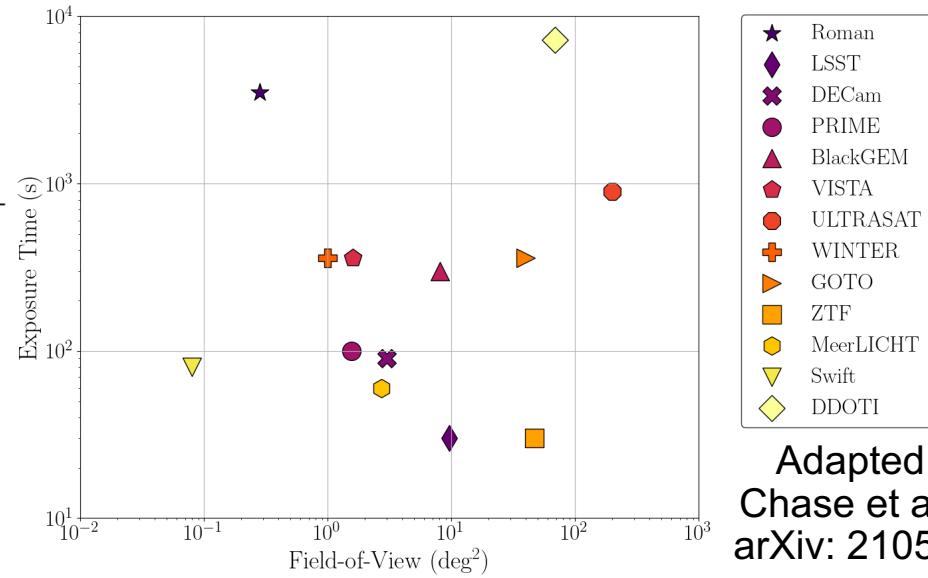


May be useful to exclusively  
search for KNe in i-band

# Wide-Field Instruments

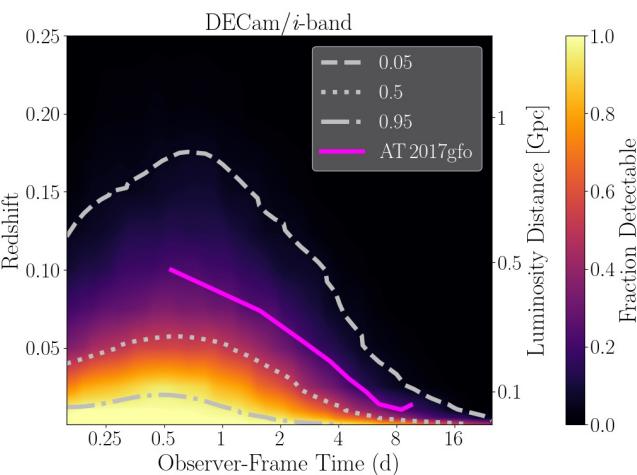
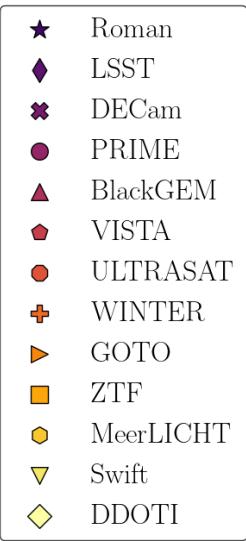
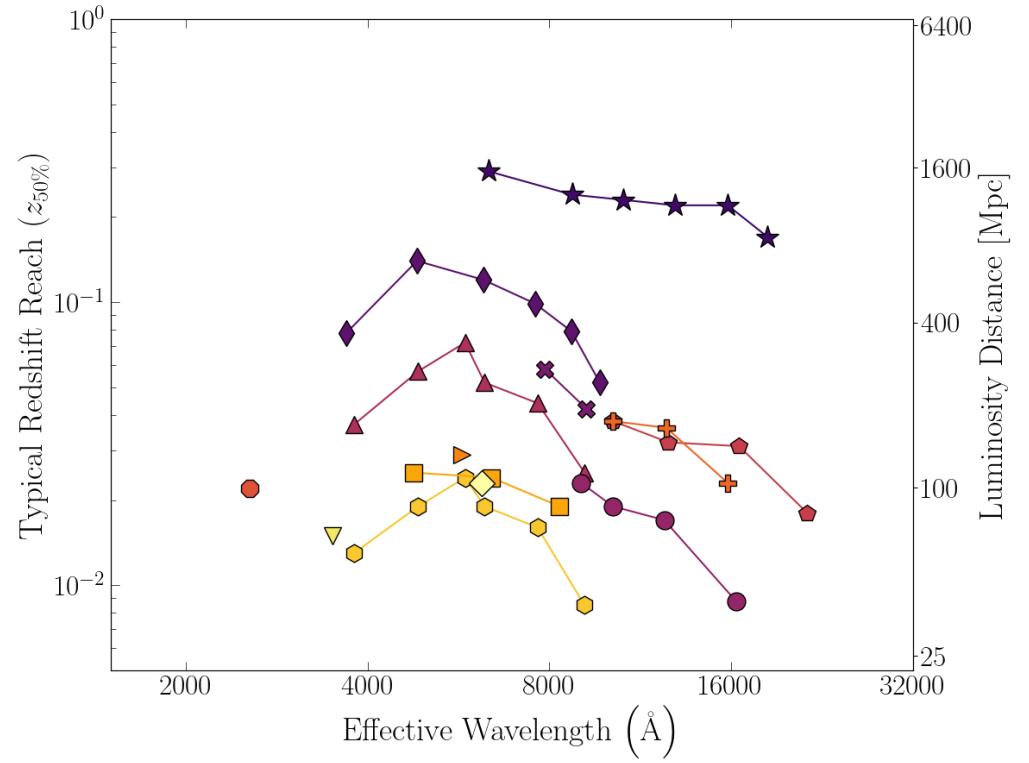
**Table 1.** Kilonova detectability metrics for a wide-field instruments.

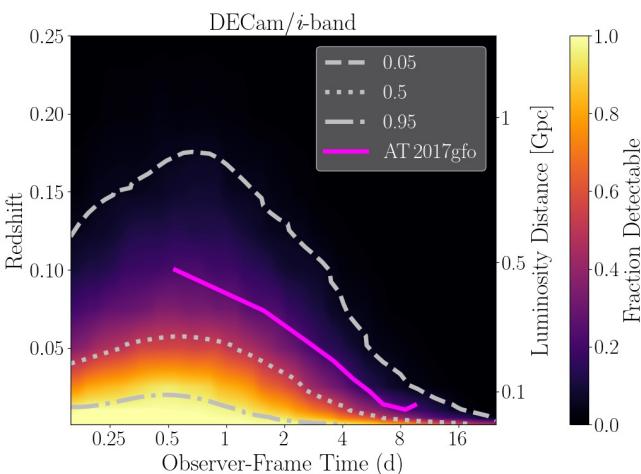
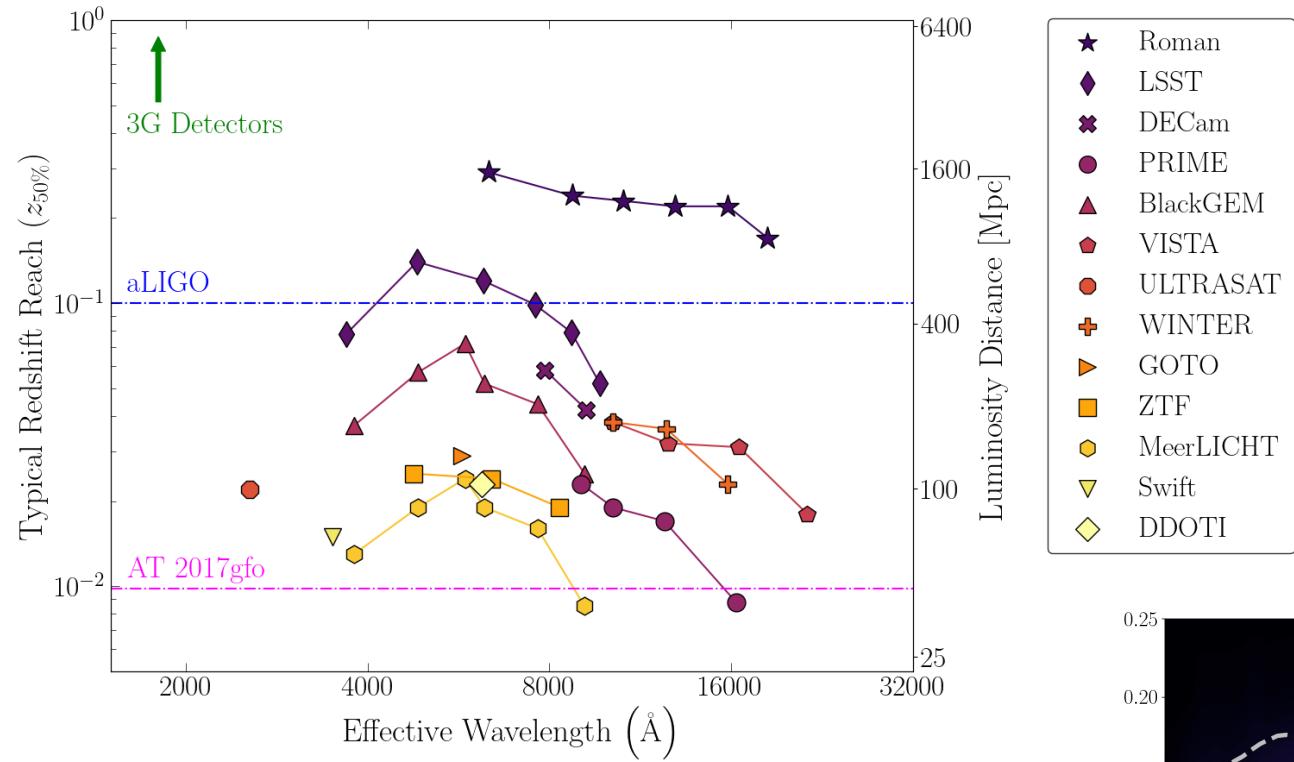
Instrument	FoV (deg <sup>2</sup> )	Exp. Time (s)	Filters
BlackGEM	8.1	300	<i>ug(q)riz</i>
DDOTI	69	7200	<i>w</i>
DECam	~3	90	<i>iz</i>
GOTO	40	360	<i>L</i>
LSST	9.6	30	<i>ugrizy</i>
MeerLICHT	2.7	60	<i>ug(q)riz</i>
PRIME	1.56	100	<i>ZYJH</i>
Roman	0.28	67	<i>RZYJHF</i>
<i>Swift</i> /UVOT	0.08	80	<i>u</i>
ULTRASAT	200	900	<i>NUV</i>
VISTA	1.6	360	<i>YJHK<sub>s</sub></i>
WINTER	1.0	360	<i>YJH<sub>s</sub></i>
ZTF	47	30	<i>gri</i>

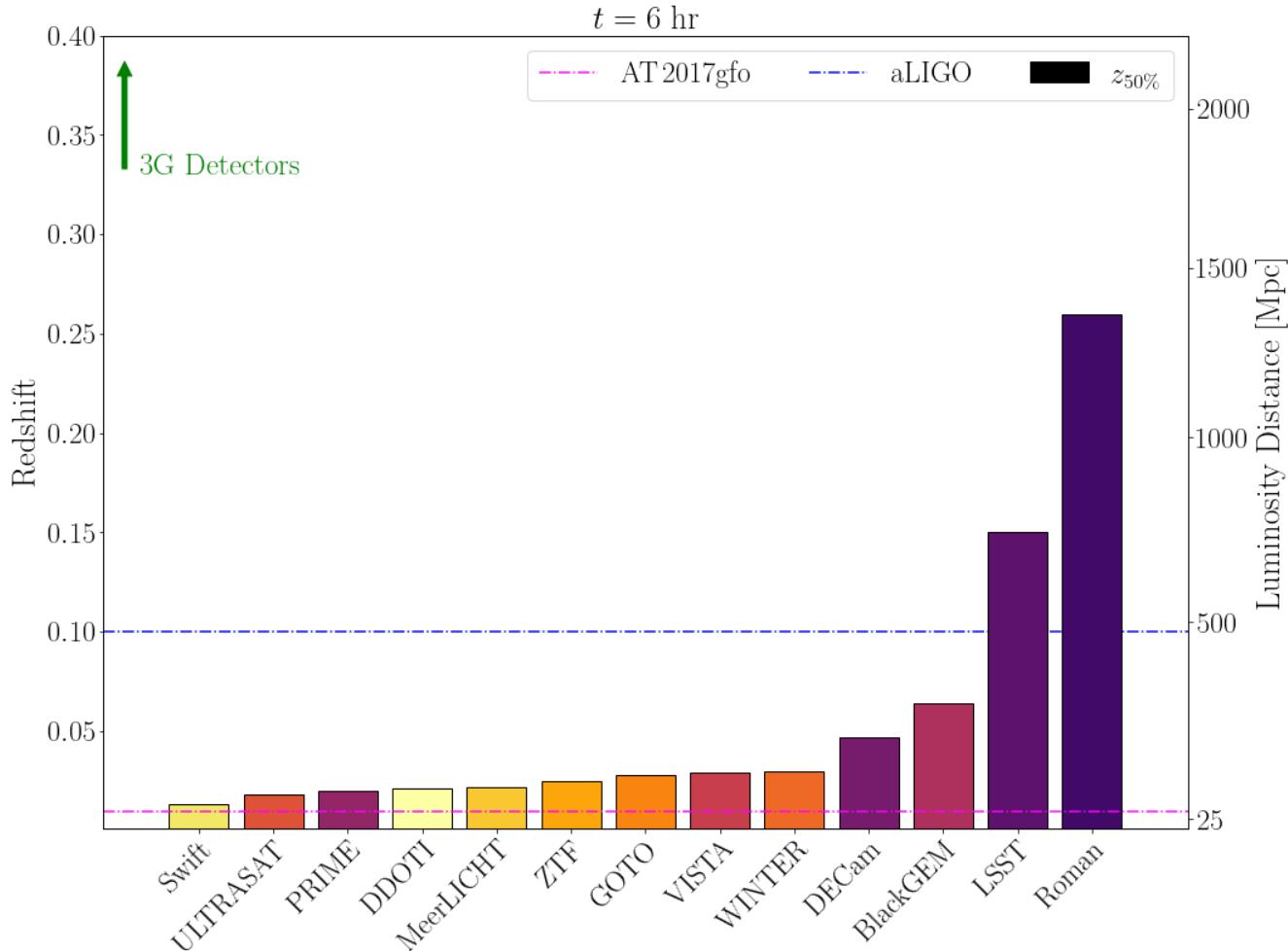


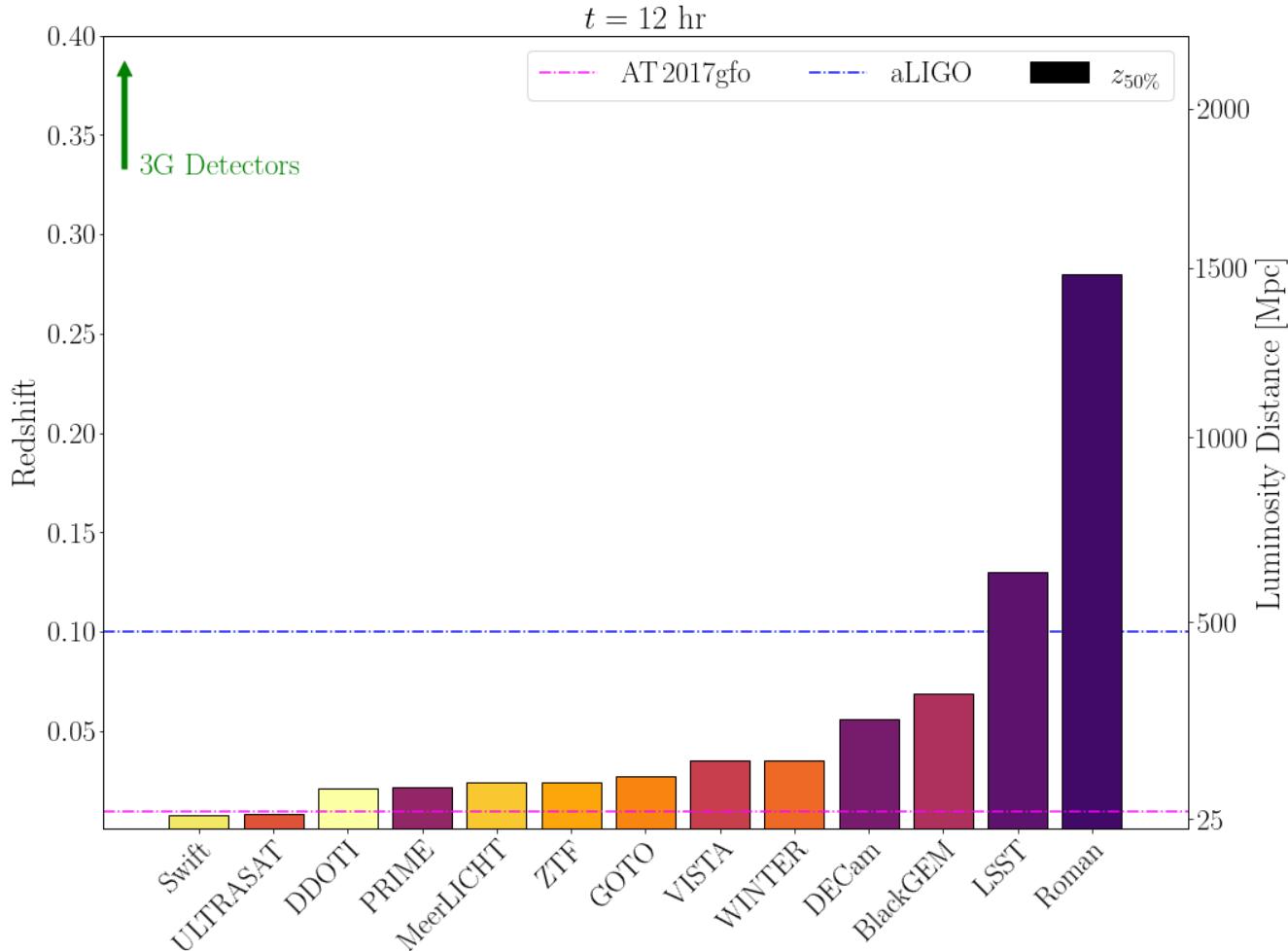
Adapted from  
Chase et al. 2022  
arXiv: 2105.12268

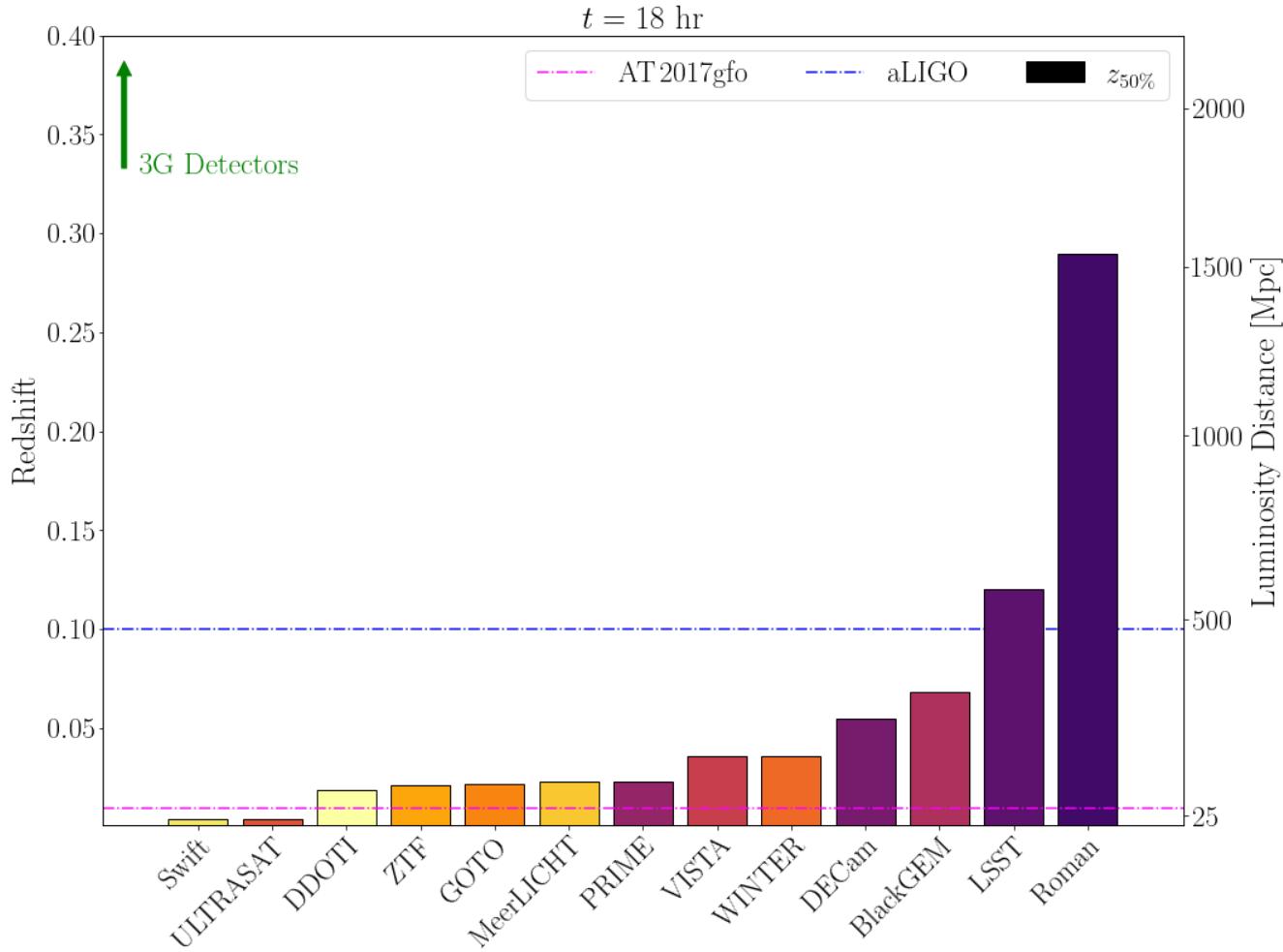
Exposure times may  
be altered to meet  
observational needs

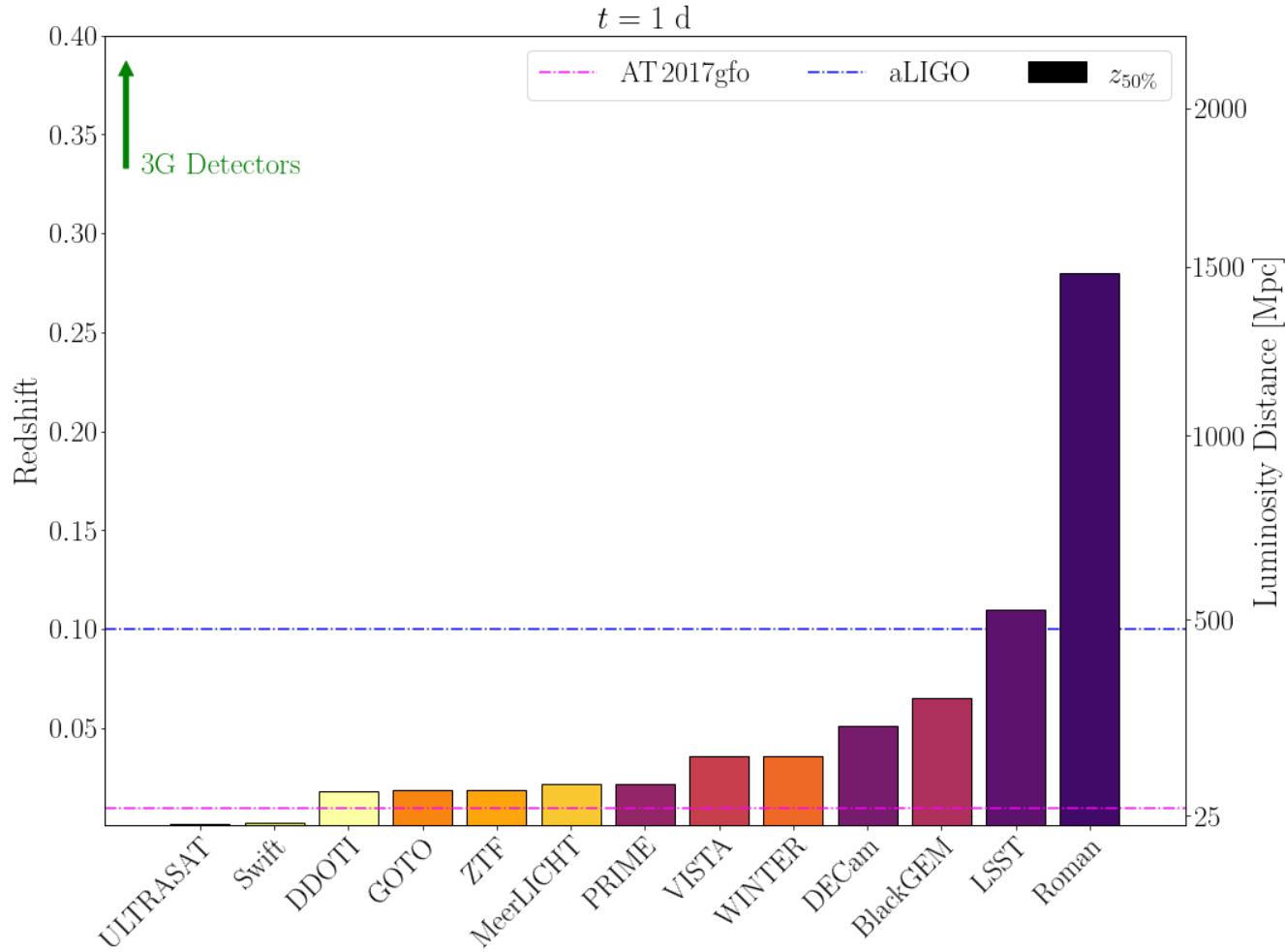


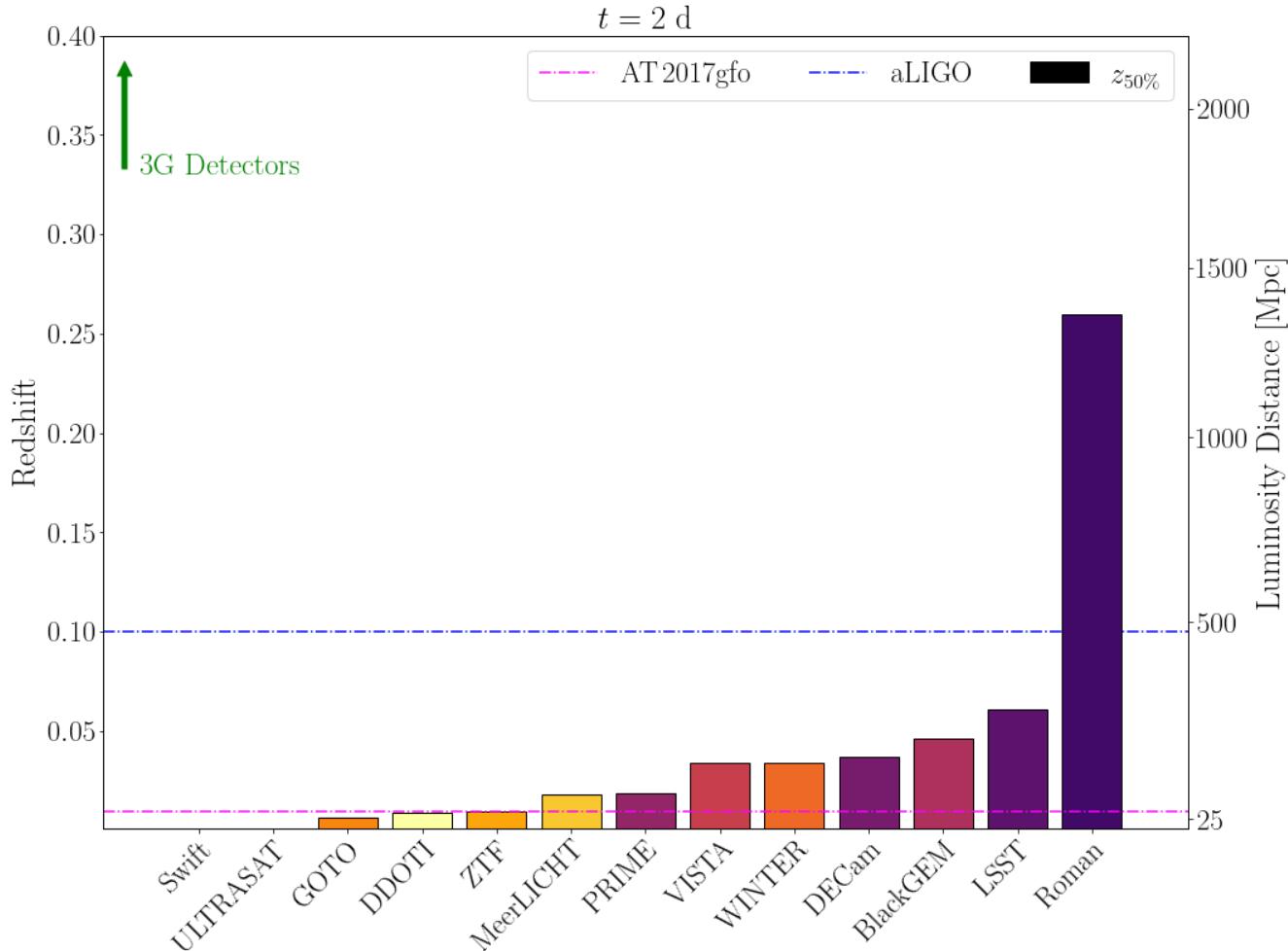


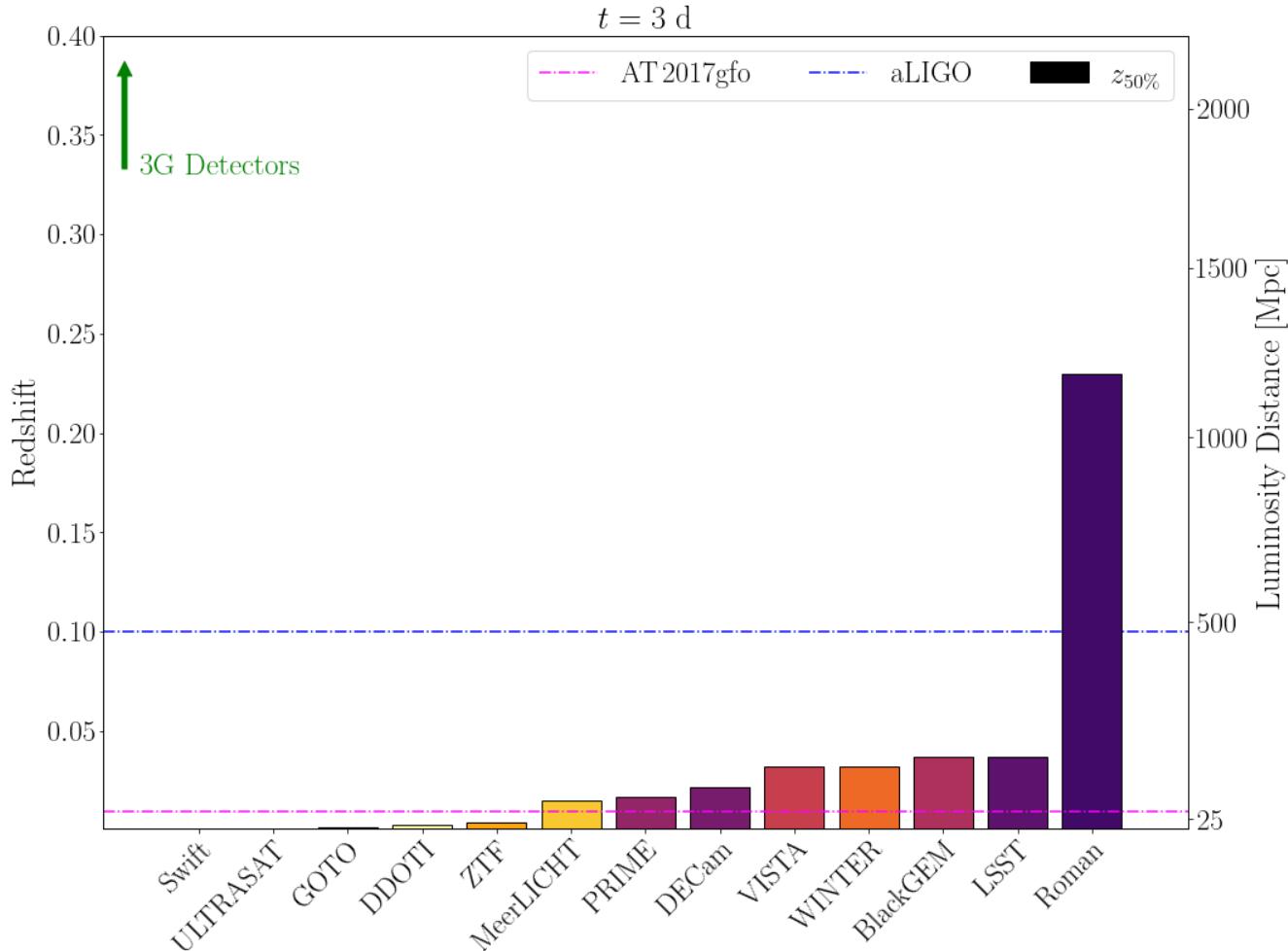


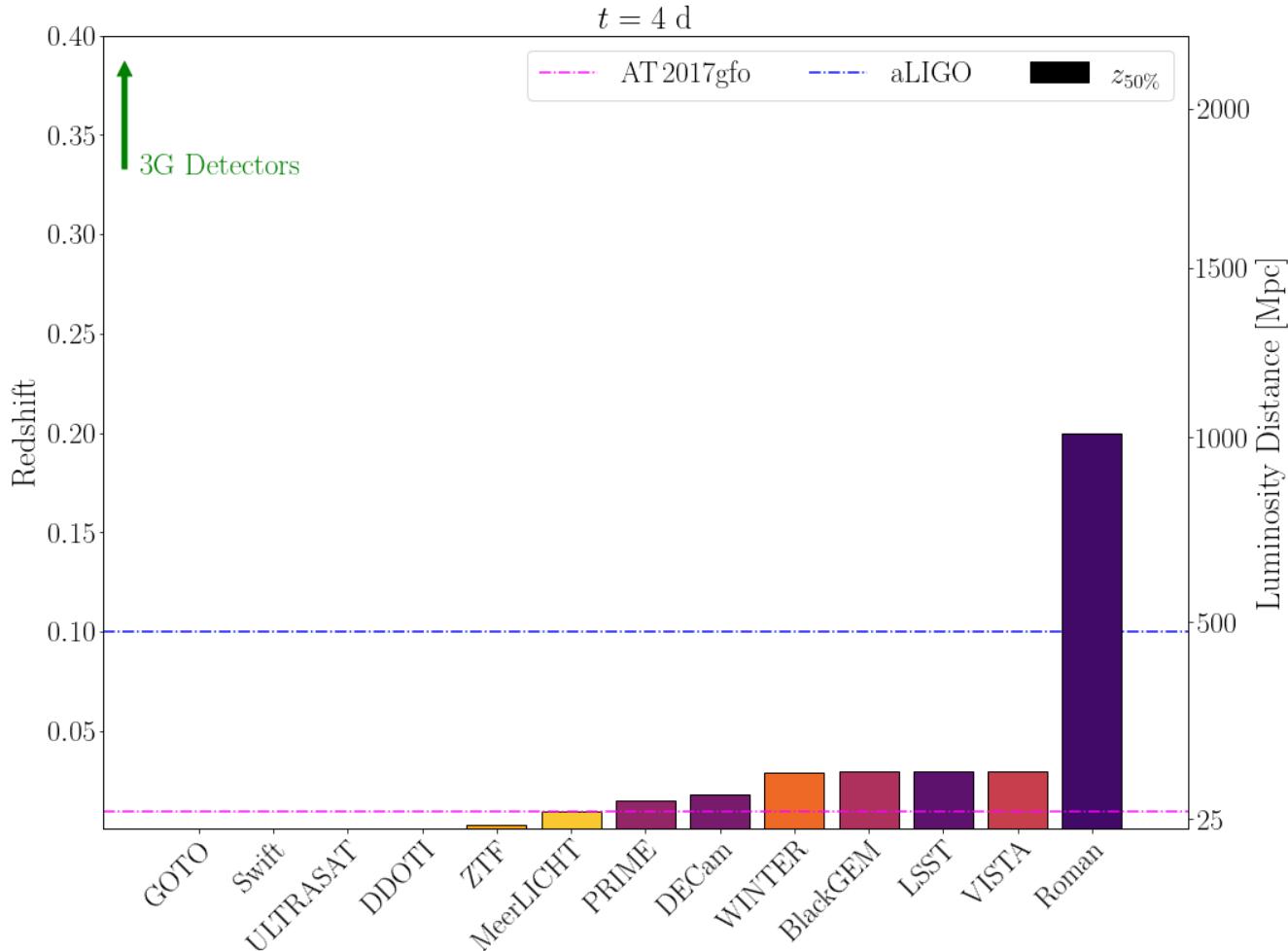


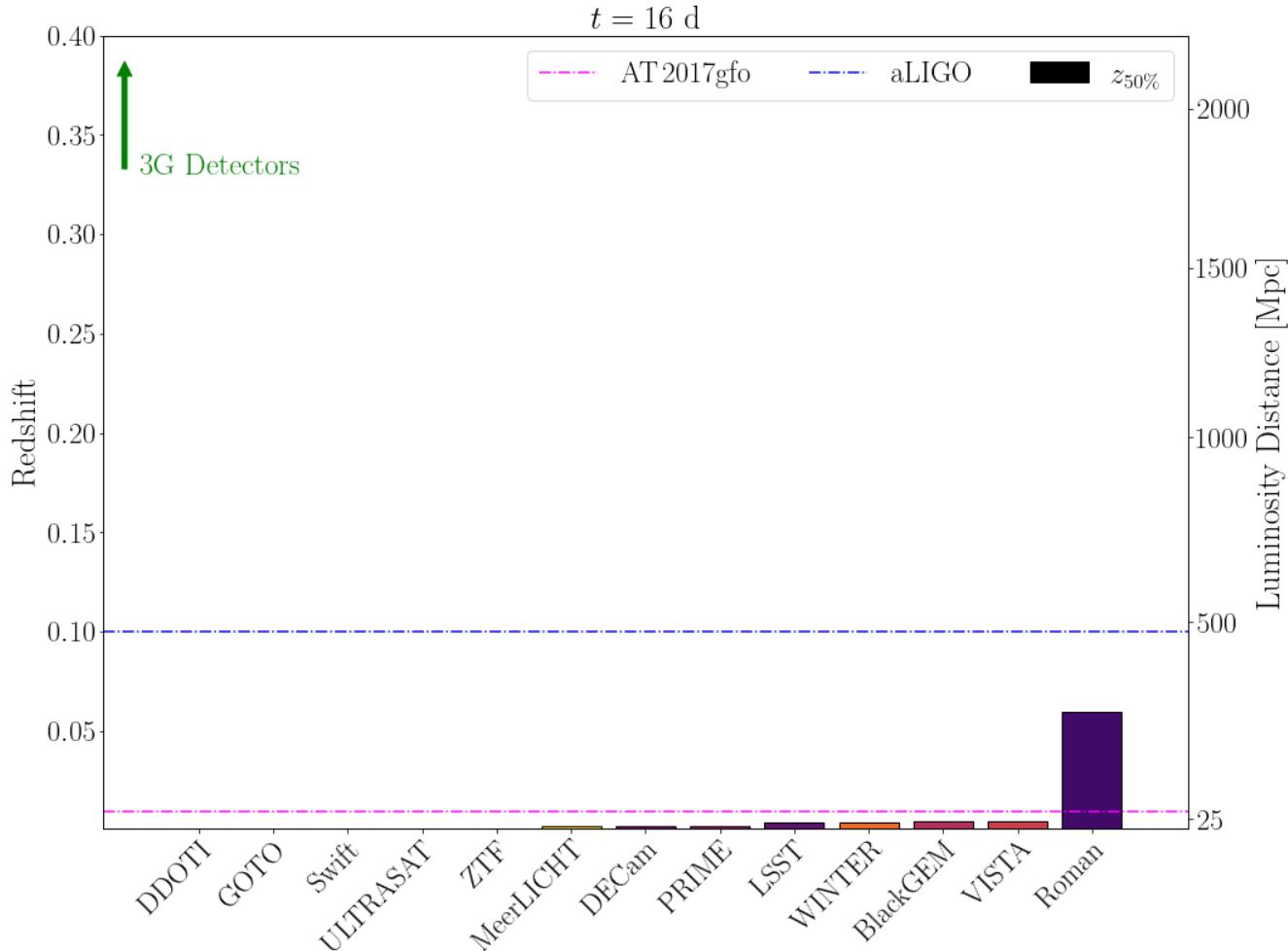












# Kilonova Detectability Conclusions

- A diverse set of instruments increase the chances of detecting and identifying a kilonova
- Early observations increase the probability of detection
- More sensitive wide-field ultraviolet instruments are needed as GW detectors reach design sensitivity
- There is a dearth of wide-field infrared instruments

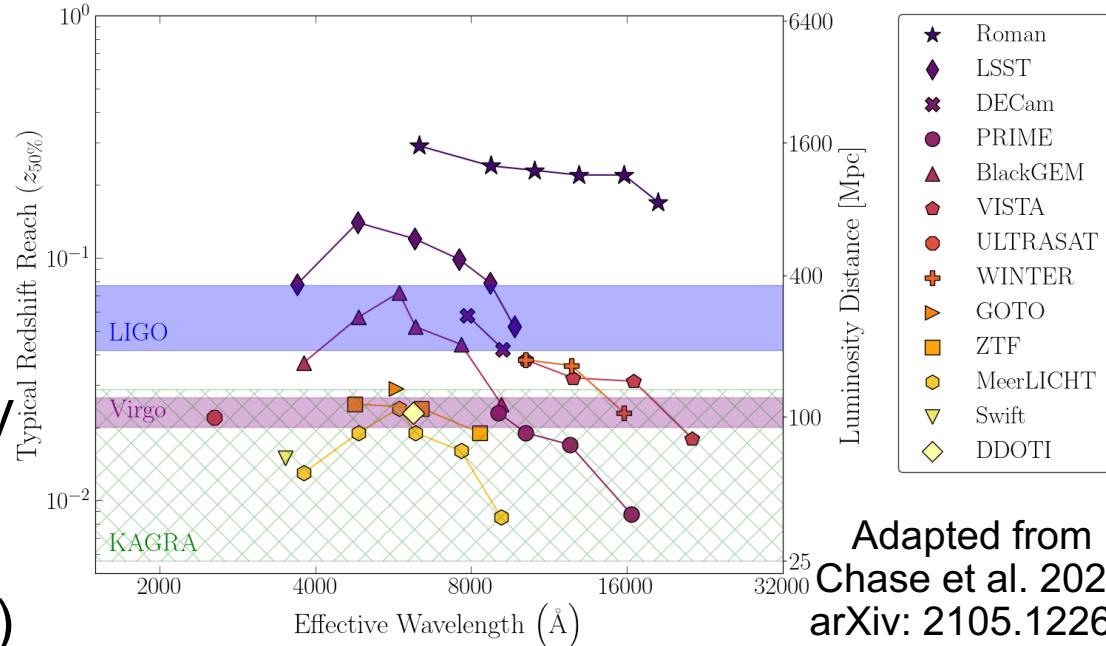
## These results are useful for...

Caveat: results are  
model-dependent

- Guiding kilonova searches following a GW detection
- Guiding kilonova searches following a sGRB observation
- Proposals for time on current and upcoming instruments
- Planning future wide-field instruments

# A Look to the Future: O4

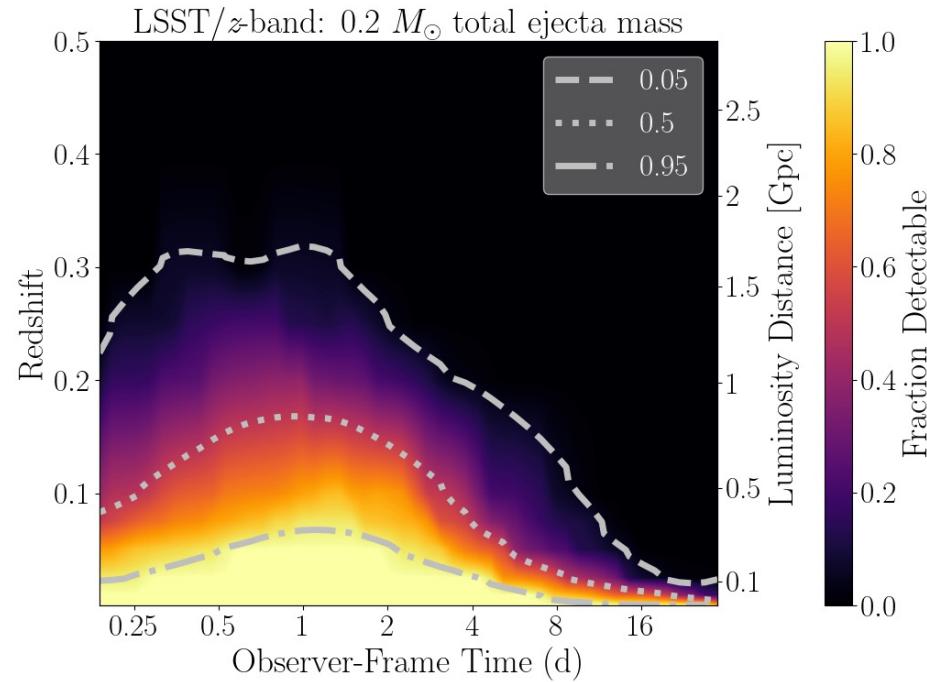
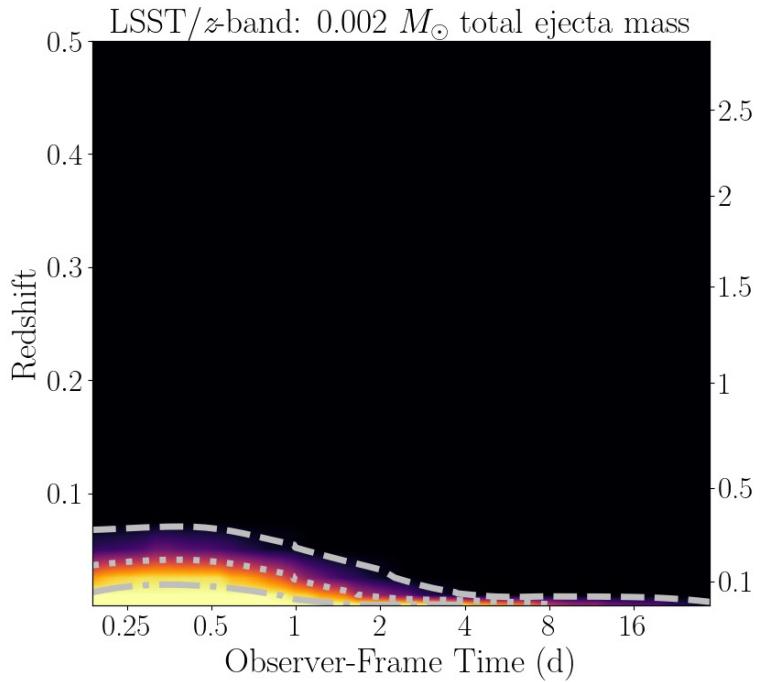
- Fourth GW observing run (O4) set to begin in December 2022, at the earliest
- 12 month observing run with LIGO, Virgo, and KAGRA detectors
- Between 0 and 62 binary neutron star mergers anticipated, with a median of 10 (LVK 2020)



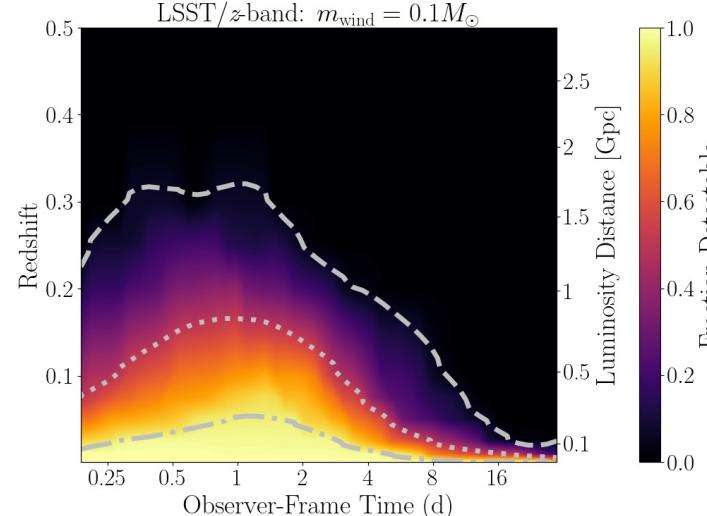
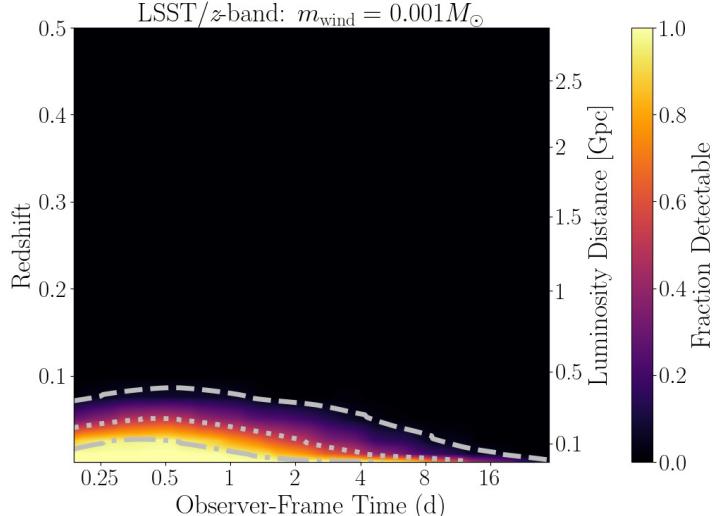
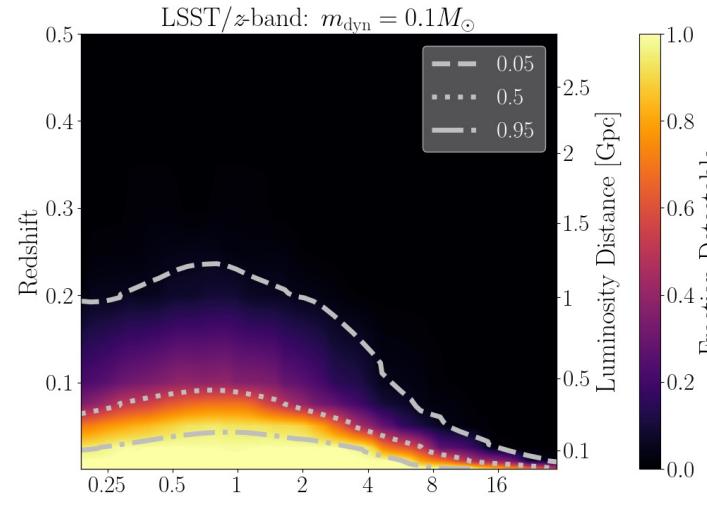
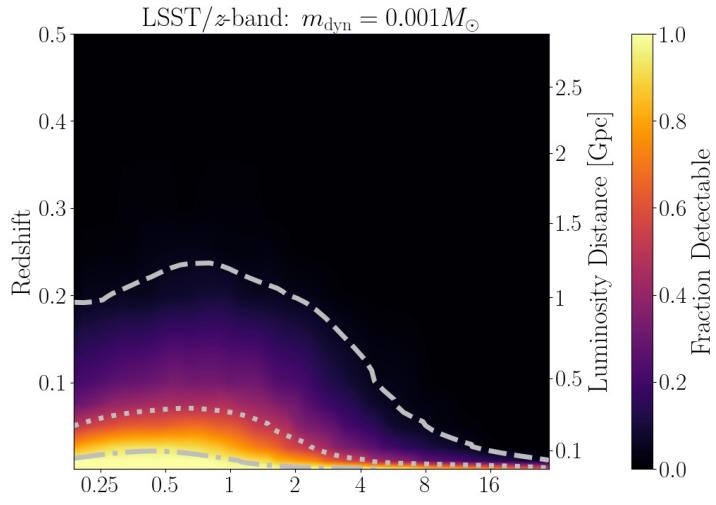
Adapted from  
Chase et al. 2022  
arXiv: 2105.12268

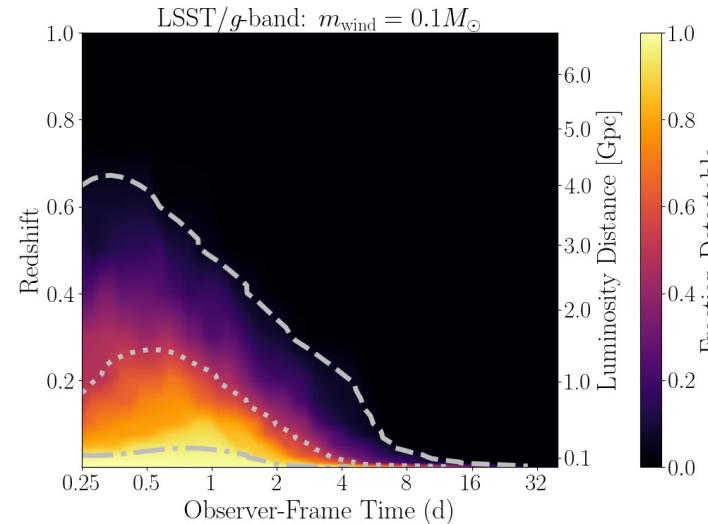
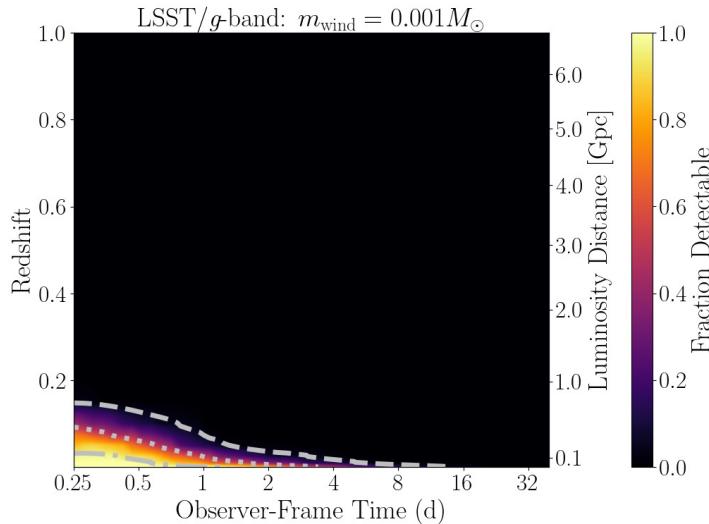
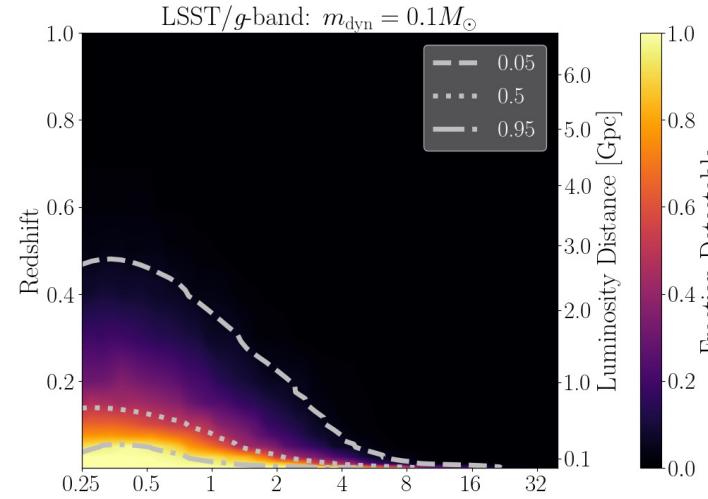
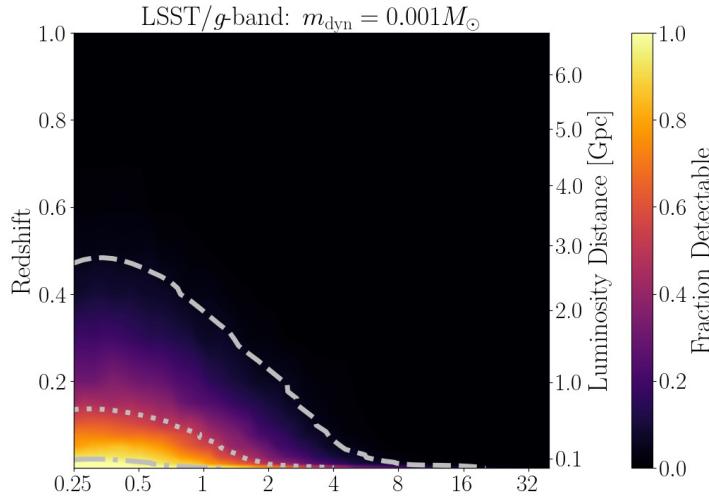
# Extra Slides

# Dependency on Kilonova Parameters

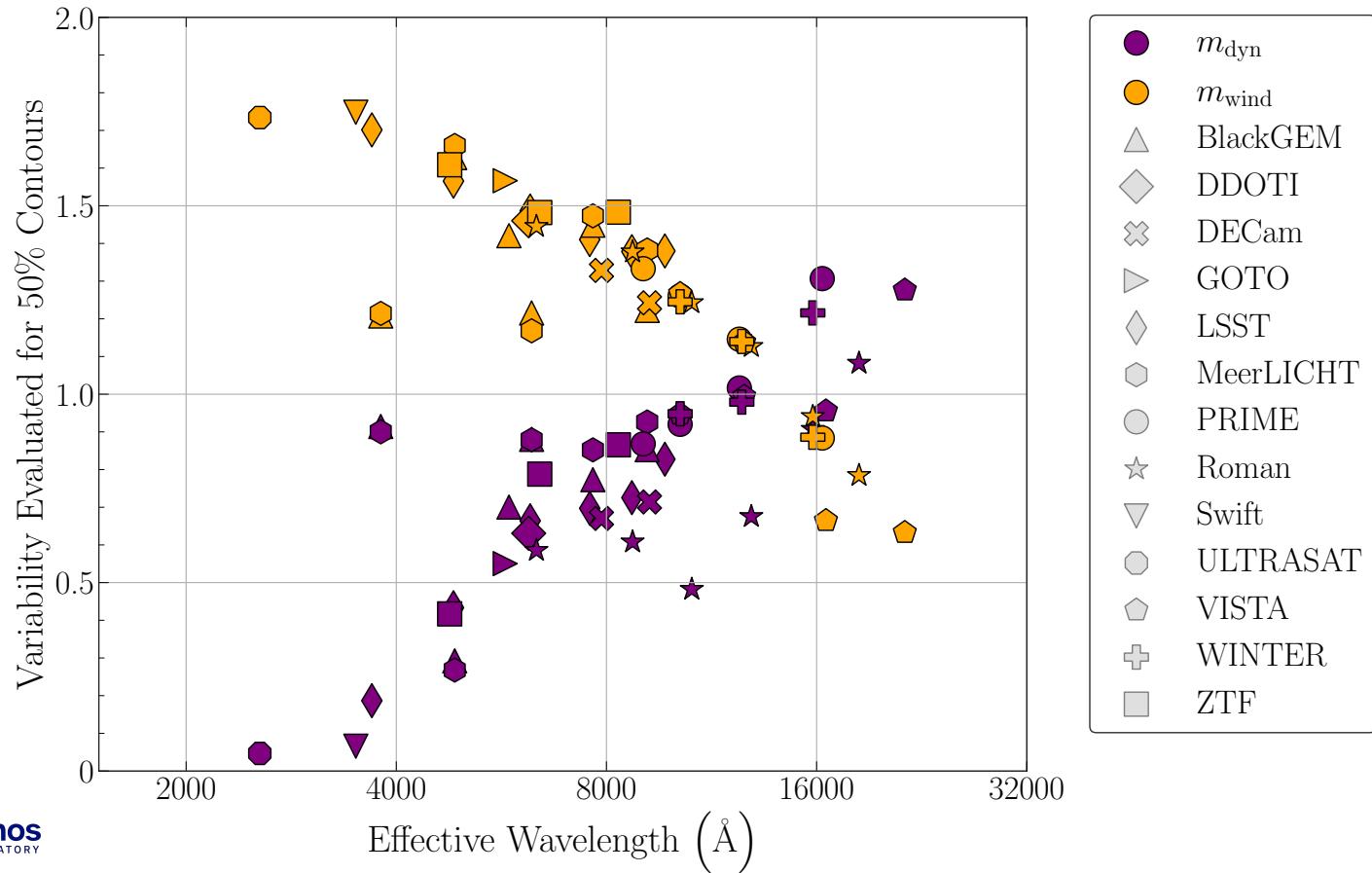


Generally, kilonovae with higher ejecta masses are detectable at larger redshifts.

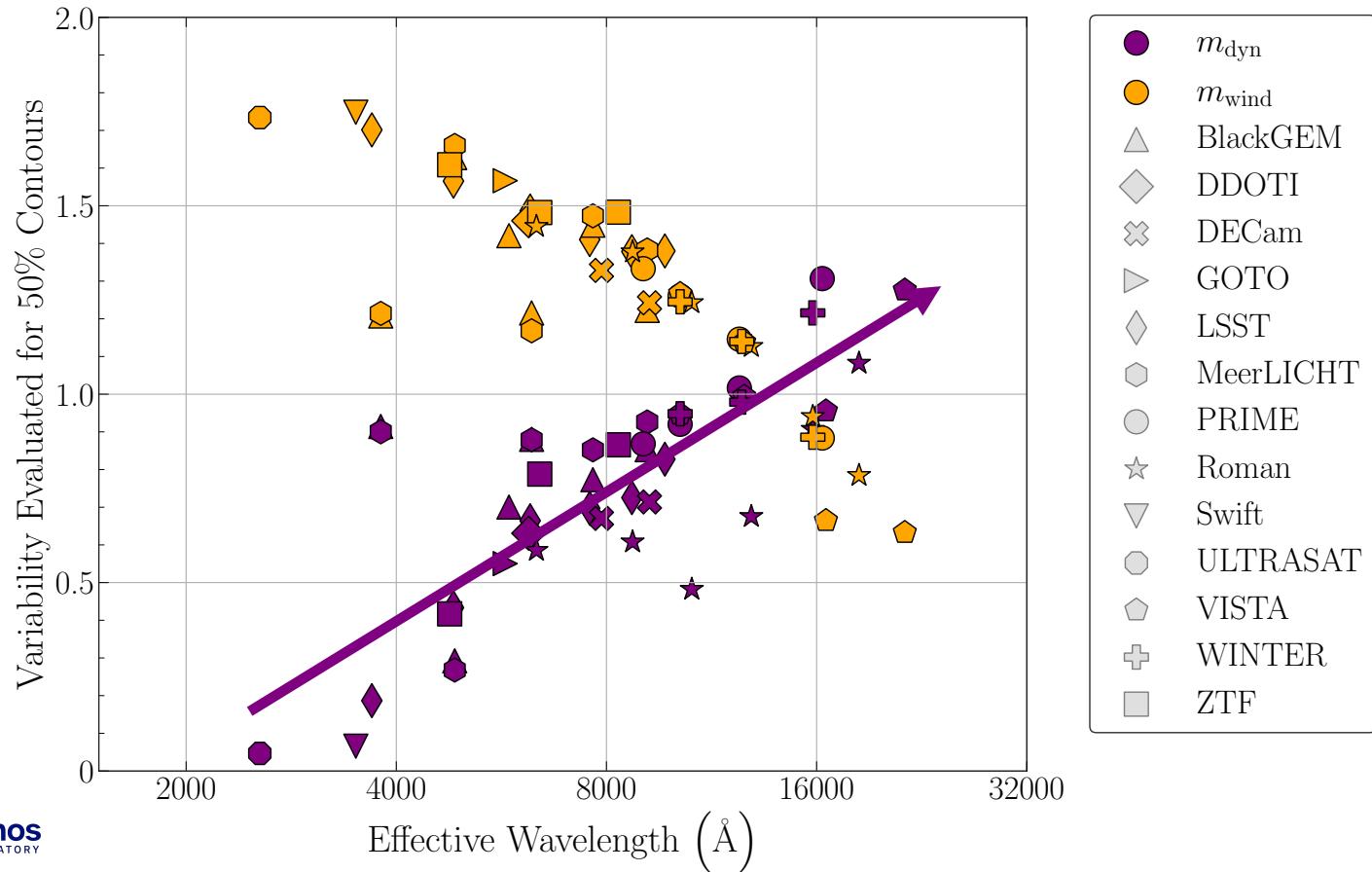




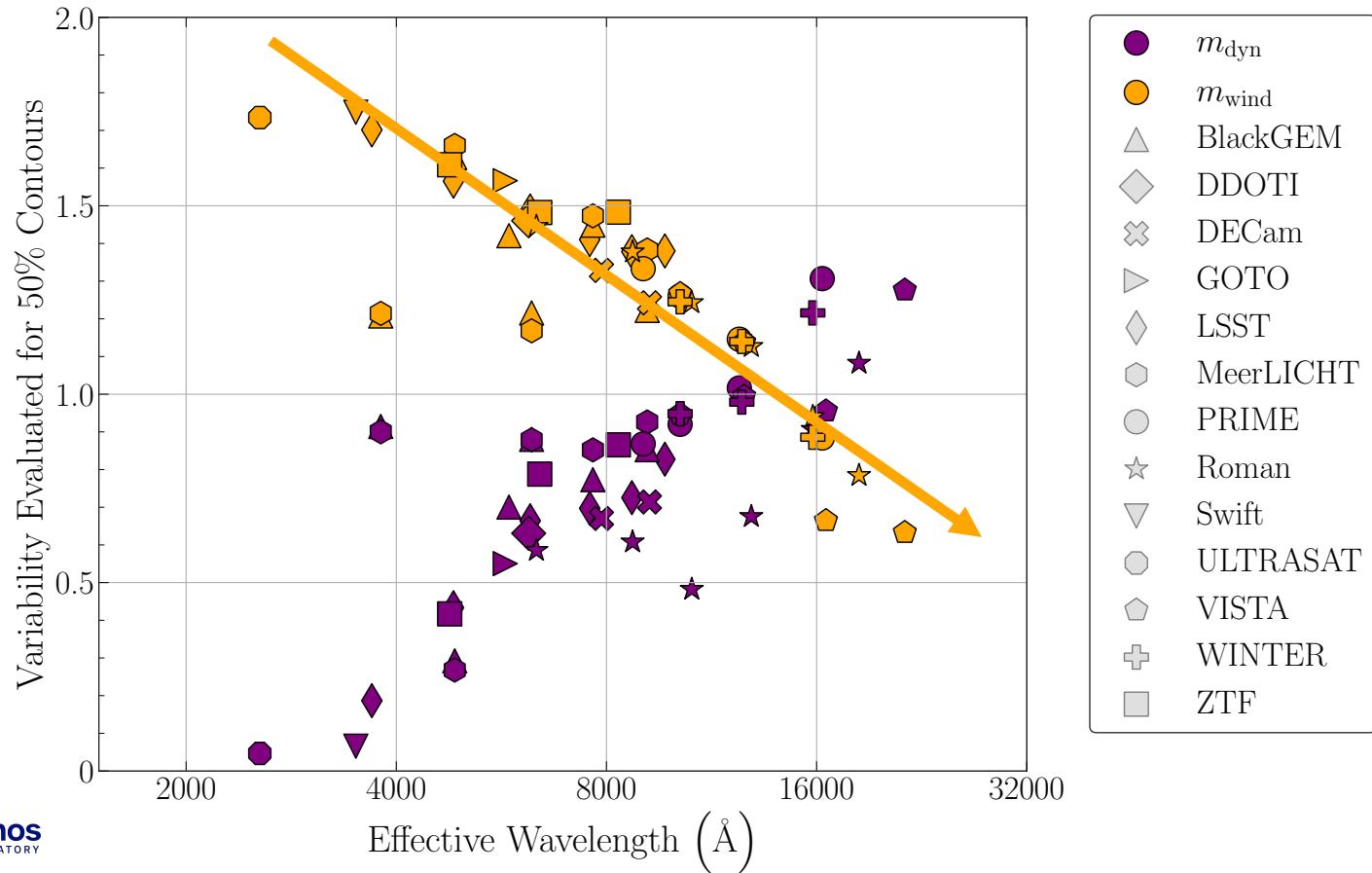
# Dependency on Kilonova Parameters



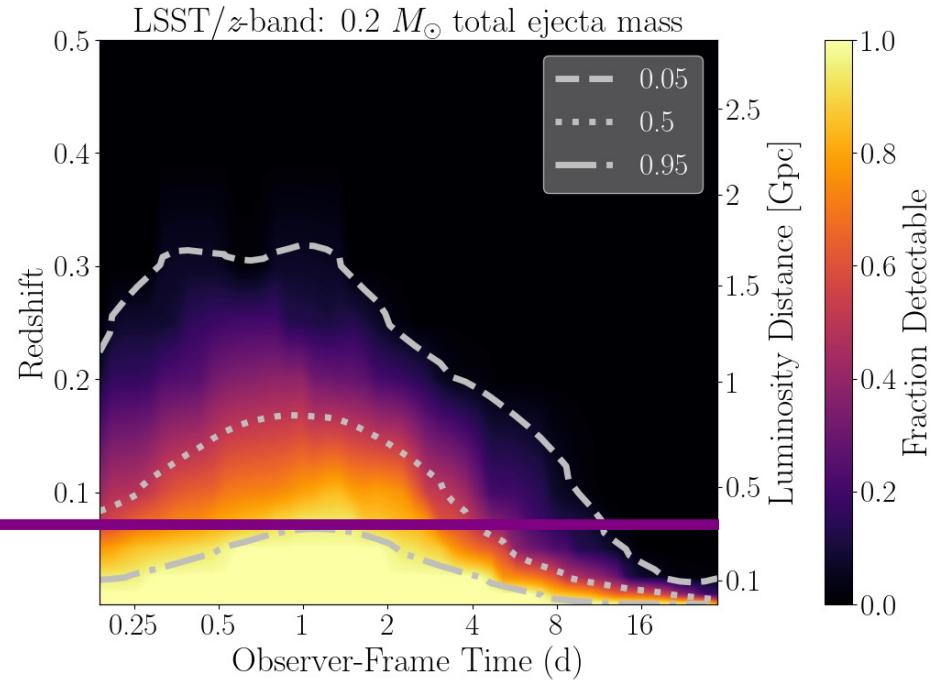
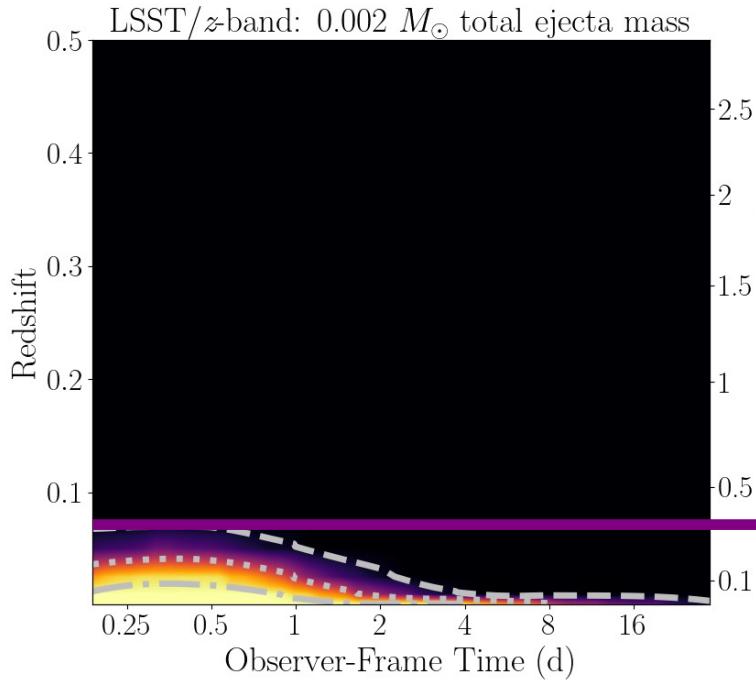
# Dependency on Kilonova Parameters



# Dependency on Kilonova Parameters



# Inferring Properties from Non-Detections



Non-detection in  $z$ -band 1 day post-merger is  
consistent with low total ejecta masses at this redshift